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DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

MICA

BY

F. W. HORTON

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By F. W. Horton[2]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6822."

[2] Mining engineer, U. S. Bureau of Mines.

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INTRODUCTION

This paper covers the salient features of the occurrence and mining of sheet mica in the United States and the preparation of mica for market; presents the results of a study of the physical properties of domestic and foreign micas, which the author hopes may be of interest to every mica user, as it definitely answers many questions as to the suitability of various micas for particular purposes; and discusses mica-trade conditions and the future outlook for the domestic mica industry.

ACKNOWLEDGMENTS

The author takes pleasure in acknowledging his indebtedness to J. R. Thoenen, of the United States Bureau of Mines, under whose guidance the work reported herein was performed, and to Frank L. Hess, also of the Bureau, for information on the geological and mineralogical characteristics of mica-bearing pegmatites.

Special acknowledgment is due the late Dr. George K. Burgess, former director of the National Bureau of Standards, and to Dr. L. J. Briggs, the present director, for providing the facilities of their organization in performing the physical tests described herein. The author is also indebted to the following physicists of the Bureau of Standards, who directed and performed the tests: Dr. F. B. Silsbee, A. B. Lewis, F. R. Caldwell, and E. L. Hall.

Thanks are due to Dr. O. E. Kiessling and B. H. Stoddard, of the United States Bureau of Mines, for their kindness in supplying data on the production and consumption of mica.

Acknowledgment is made to all individuals and companies who supplied micas for physical tests, allowed the writer to examine their mica deposits and mica-working plants, or otherwise assisted him.

Valuable help was given the writer by Herbert Brown, J. Fuller Brown, and B. C. Grindstaff, of the Asheville Mica Co., Biltmore, N. C., in studying the mica deposits of North Carolina. The writer is also indebted to Douglas B. Sterrett, Joseph Ulmer, and W. M. Myers for much information that has been taken from their respective reports on various phases of the mica industry.[3]

HISTORY OF THE MICA INDUSTRY IN THE UNITED STATES

Ornaments made from mica found in graves of the mound builders in the Mississippi Valley and extensive aboriginal workings in the Southern Appalachian States offer conclusive proof that mica was mined in the United States before the arrival of white men. Mining, of course, was restricted to the weathered portions of pegmatites in which the feldspars had been kaolinized and the rock rendered soft enough to be mined with primitive tools. What peoples engaged in this ancient mining or what uses were made of the mica are unknown, but it is assumed that the mica was used largely for ornaments. In Europe mica has been used for 2 or 3 centuries as glazing for windows, and in India for even longer in making lanterns and ornaments and as a medicine.

In the United States the Ruggles mine in Grafton County, N. H., which was opened in 1803, was the first known mica deposit operated on a commercial scale. The product was utilized almost exclusively for stove windows. Soon afterward other deposits were opened in New Hampshire, and mining was carried on irregularly until shortly after the Civil War, when the first large-scale production was made in North Carolina and mining in New Hampshire declined. North Carolina continued to be the leading producer of mica for many years, although intermittent mining of mica on a considerable scale has been carried on in many other States, notably Virginia, South Dakota, New Mexico, Idaho, Georgia, and Connecticut. During the last decade New Hampshire has alternated with North Carolina as the leading producer of sheet mica; the production of scrap grades in North Carolina, however, has far exceeded that in New Hampshire.

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[3] Sterrett, D. B., Mica Deposits of the United States: U.S. Geol. Survey Bull. 740, 1923, 342 pp.

Ulmer, Joseph, International Trade in Mica: Bureau of Foreign and Domestic Commerce, 1930.

Myers, W. M., Mica. Pt. I, General Information: Inf. Circ. 6205, Bureau of Mines, 1929, 37 pp.

Although the United States is the world's largest consumer of mica, its market for sheet mica has been dominated for 40 years by imports from India, except for brief periods during which import tariffs were high enough to prevent such control. India has excellent deposits of mica and exceedingly cheap labor, which has been utilized in making a splendidly prepared and closely graded mica with which the domestic product cannot compete on an even basis. The process of making mica plate or mica board by cementing thin films or splittings of mica with shellac or other suitable binders was discovered in 1894, and as the built-up board was easily fabricated it gave considerable impetus to the use of mica in the electrical industries.

Because of its cheap labor and supplies of suitable mica, India immediately captured the world market for splittings and today produces virtually all muscovite splittings used in the United States and Europe. Various methods of splitting mica by machine have been devised, but none has been notably successful in splitting muscovite. For several years a small production of phlogopite or amber splittings has been made in the United States by machine methods from mica recovered from Canadian mine dumps, but the bulk is produced by hand from Madagascan and Canadian phlogopite. The domestic mica industry exists today solely by virtue of a protective import tariff.

GENERAL DESCRIPTION OF MICA

The term "mica" from the Latin "mico", meaning to sparkle or glisten, is a group name for a number of aluminum silicate minerals characterized by their high reflection and a basal cleavage so perfectly developed that they can be split into exceedingly thin laminae, which are more or less tough, elastic, and transparent according to variety. The micas are primarily silicates of aluminum with potassium (or sodium) and hydrogen; all yield water on ignition, usually 4 to 6 percent. They often contain magnesium and ferrous iron and in certain instances sodium, lithium, chromium, and ferric iron. Fluorine is prominent in some species and probably occurs in most if not all of them. Barium, manganese, titanium, and boron occur in some varieties. Mineralogists recognize 8 distinct species of true mica, as shown in the following table, but of these only the first 5 are commercially important.

Species	Theoretical chemical formula
Muscovite	$H_2KAl_3(SiO_4)_3$
Phlogopite	$HK(MgF)_3Mg_3Al(SiO_4)_3$
Biotite	$(HK)_2(MgFe^{II})_2(AlFe^{III})_2(SiO_4)_3$
Lepidolite	$KLi\,Al(OHF)_2\,Al(SiO_3)_3$
Roscoelite	$H_8K(MgFe)(AlV)_4(SiO_3)_{12}$
Zinnwaldite	$(KLi)_3FeAl_3Si_5O_{16}(OH,F)_2$?
Paragonite	$H_2NaAl_3(SiO_4)_3$
Lepidomelane	$HK_2F_3^{II},\ Fe_6^{III}6Al3(SiO_4)_9$

Most of these formulas have not been definitely established; in fact, all species of mica vary considerably in composition, giving rise to numerous varieties. However, the for-

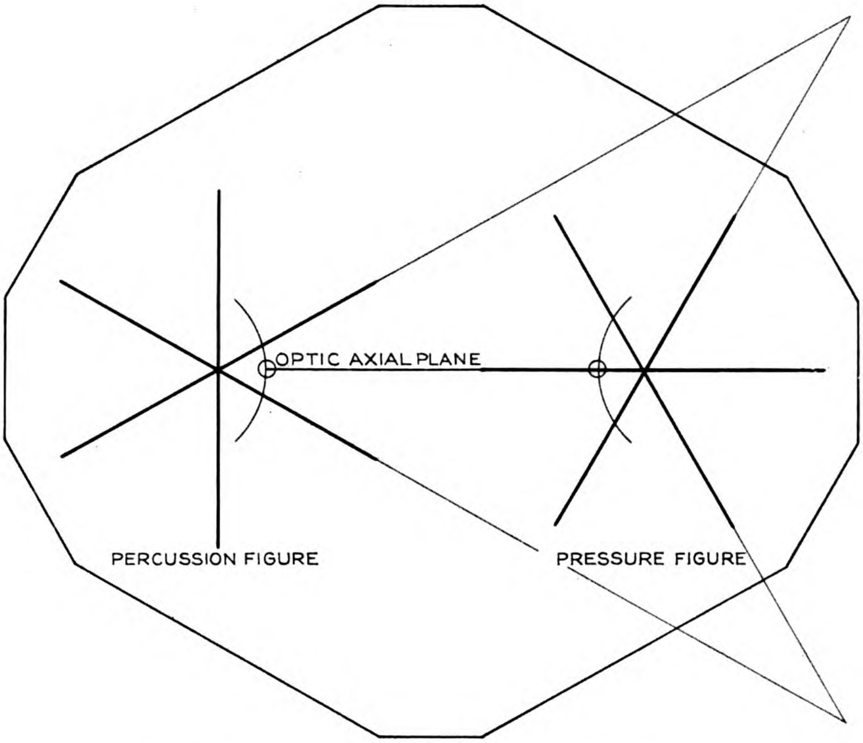

Figure 1.—Positions of the percussion and pressure figures in muscovite. (After W. T. Schaller.)

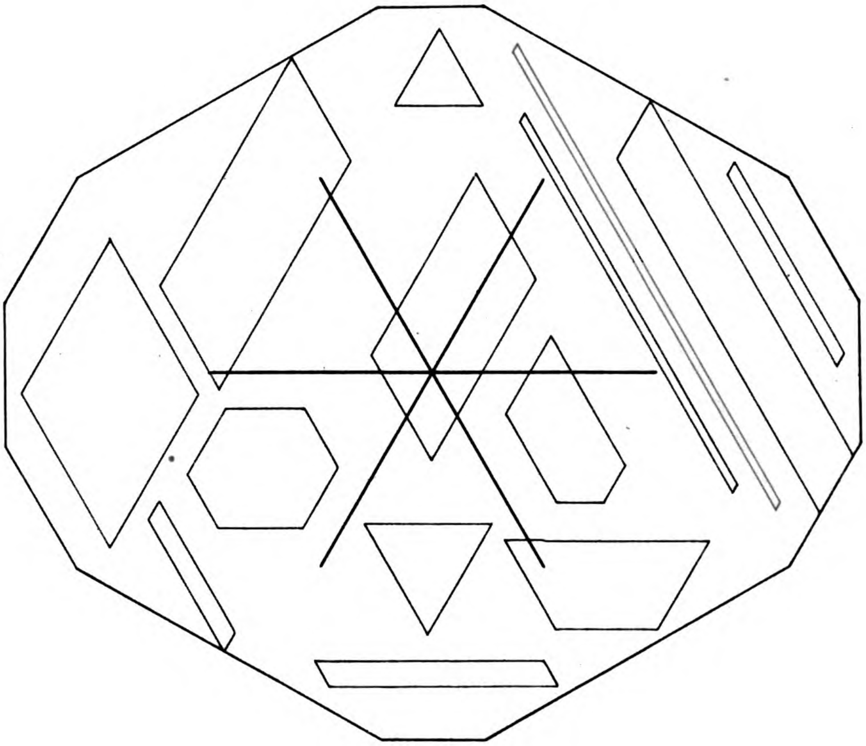

Figure 2.—Outlines of all polygons formed by parting planes in muscovite follow the direction of the rays of the pressure figure. (After W. T. Schaller.)

mulas show the approximate composition of the typical species and indicate why muscovite is commonly called potash mica; biotite, iron mica; lepidolite, lithium mica; and paragonite, sodium mica in accordance with the prominence of these elements in the micas. Mica crystallizes in the monoclinic system but with a close approach to either rhombohedral or orthorhombic symmetry. In all cases the plane angles of the base are close to 60° or 120°. A cleavage plate shows an axial interference figure which for pseudorhombohedral micas is uniaxial or nearly so, as with biotite. The axial angle of phlogopite is usually 10° to 12°, but for muscovite, lepidolite, and paragonite the angle is commonly 50° to 70°. All species of mica may be referred to the same fundamental axial ratio with an angle of obliquity varying but slightly from 90°. They commonly show the same forms and frequently intercrystallize in parallel position. Thin sheets of muscovite containing areas of biotite or vice versa are common; lepidolite and muscovite intercrystallize in the same way.

A six-rayed percussion figure is produced in all micas by striking a cleavage plate with a small, dull point. A dulled pin struck sharply on the head will produce the figure in a thin plate. Two lines of the figure approximately parallel the prismatic edges of the crystal, and the third or strongest parallels the clinopinacoid. The percussion figure may be used to establish the crystallographic orientation when crystal faces are lacking.

A second series of lines at angles of about 30° with those of the percussion figure may be developed more or less distinctly by pressure of a dull point on a thin lamina, forming the so-called pressure figure.

Of the five commercial micas muscovite, phlogopite, and biotite are used solely because of their physical properties, whereas lepidolite and roscoelite are mined as ores of lithium and vanadium, respectively.

MUSCOVITE

Mineralogy

Muscovite or potash mica is the most important mica of commerce and is the only one mined extensively in the United States. It usually occurs as tabular crystals, hexagonal or rhombic in outline, with prismatic faces more or less rough and striated horizontally. These crystals may be 4 or 5 feet in diameter and weigh 1 or 2 tons, or they may be less than 1/16 inch across, aggregated in stellate, feathery, or globular forms. In fact, the crystals may be cryptocrystalline. Muscovite has an eminent basal cleavage and also secondary cleavages, better described as parting planes, which cut the crystals at angles of 60° to 70° with their basic cleavage. These parting planes may extend entirely through a crystal or only part of the way either across the cleavage face or through the thickness of the crystal. Figure 1[4] shows the positions of the percussion and pressure figures of muscovite with respect to the crystal faces and to each other. Figure 2[5] shows that the outlines of the ribbons, triangles, acute rhombs, and other polygons formed by parting planes follow the direction of the rays of the pressure figure and not of the percussion figure.

Thin laminae of muscovite are transparent, flexible, elastic, and usually colorless. Sheets 1/8 inch or more in thickness, however, usually show a distinct color - some shade of gray, brown, red, yellow, or green. The color, probably due to minute inclusions of metallic oxides, classifies the mica as "ruby", "rum", "green", "smoked", etc. Zonal coloration with a definite relation to crystal structure is found occasionally.

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[4] Schaller, W. T., U.S. Geological Survey Report D-269 to Scott Turner, Director, U.S. Bureau of Mines, Oct. 30, 1933.

[5] See footnote 4.

Muscovite ranges in hardness from 2 to 2.5. The harder varieties usually are less flexible than the softer, which has a direct bearing on the suitability of the mica for certain uses. Muscovite has a specific gravity of 2.76 to 3, a colorless streak, and commonly a vitreous luster. The index of refraction ranges from 1.56 to 1.59. Muscovite is optically negative and normally has an axial angle of about 70°, which diminishes to 50° in varieties high in silica. Usually it is feebly pleochroic, but in some deep-colored varieties pleochroism is pronounced. It has a rather strong double refraction.

Muscovite shares with phlogopite the reputation of being the best dielectric known and is an excellent thermal insulator. Under normal conditions it is one of the most stable of minerals. It is virtually unaffected by weathering and is not decomposed by acids. It may be heated to 400°C. without change; at this temperature, however, it begins to give up minute quantities of its water of crystallization, and at 700°C. normal muscovites lose about 1/10 percent of their weight. As dehydration progresses the mica swells, loses its transparency, and becomes brittle.

The following table shows analyses of typical muscovites:

TABLE 1.- Composition of muscovite from various localities[1]

	Theoretical	Alexander County, N. C.	Auburn, Maine	Haddam, Conn.	Bengal, India
SiO_2	45.2	45.40	44.48	45.05	45.57
Al_2O_3	38.4	33.66	35.70	30.57	36.72
K_2O	11.8	8.33	9.77	10.23	8.81
Na_2O		1.41	2.41	2.13	.62
Fe_2O_3		2.36	1.09	1.14	.95
FeO			1.07	1.73	1.28
MgO		1.86	Trace.	.97	.38
CaO			0.10		.21
Li_2O					.19
TiO_2		1.10			
F		.69	.72	1.26	.15
H_2O	4.6	5.46	5.50	6.19	5.05
	100.0	100.27	100.84	99.27	99.93

[1] Dana's System of Mineralogy, 1911, pp. 617-618.

Among the many varieties of muscovite sericite is perhaps the most common. It is a fine, scaly muscovite characterized by its silky luster and unctuous feel. It is sometimes united in fibrous aggregates and is generally regarded as of secondary origin, derived from the alteration of feldspar, kyanite, and many other aluminum silicates.

Fuchsite is a green chrome muscovite usually containing 2 to 4 percent of chromic oxide.

Occurrence

Muscovite is the most common of the micas; as an essential constituent in all granites, gneisses, schists, and other related rock it occurs in huge quantities. However, it rarely has commercial value in these forms, as it usually cannot be recovered economically. A few schists exceptionally rich in muscovite (or sericite) are milled for their mica content, and a considerable quantity of fine muscovite is recovered as a byproduct from kaolin deposits in North Carolina formed by the weathering of aplites of which the mica was an original constituent. With these exceptions all commercial muscovite is derived from pegmatites, the sole source of sheet muscovite the world over; the genesis, occurrence, and mineralogy of this interesting class of rock therefore will be discussed briefly.

Inasmuch as freedom from ruling, folding, and distortion is an essential of good sheet mica, the geologic history of regions in which mica-bearing pegmatites occur is important. Movement of the enclosing rocks either during or after the formation of mica has often rendered it valueless except for scrap through the development of ruled, wedge, tangle-sheet, and other imperfect forms. The best sheet mica is invariably found in regions of geologic stability.

Pegmatites

Pegmatites have been defined as "rocks with coarsely and unevenly crystallized and segregated minerals occurring as dikes, veins, or metamorphic masses formed from the aqueous solutions of a freezing magma or from the combination of the solutions with previously existing minerals.[6] They were the drainage systems of freezing batholiths of granite rocks that formed wet melts, whose freezing was accompanied by the expulsion of watery solutions in either gaseous or liquid form. These solutions first deposited the granitoid minerals - potash, feldspar, and quartz and in some instances muscovite or biotite or both of these micas; but in this primary form of pegmatites the mica crystals, if present, are never large enough to yield sheet mica. Owing to the long-continued flow of the solutions and possibly to changes in their character, extensive replacements of the original minerals of the pegmatites have taken place. In the replacement processes large crystals of muscovite, biotite, and sometimes lepidolite were formed, and many other minerals were introduced. Common examples are albite, tourmaline, beryl, lepidolite, spodumene, amblygonite, pollucite, cryolite, cassiterite, apatite, garnet, epidote, uranium, tantalum, and columbium minerals.

Pegmatites in which replacement has taken place are classified by Hess[7] as "metamorphic pegmatites"; this type is the sole source of sheet muscovite.

In shape and size pegmatites vary greatly. They may be dikes and veins up to 1 mile or more long and 300 feet wide, or they may be lenses, oval masses, or pipes as much as several hundred feet across or possibly only a few inches. Their mineralogical composition may change with the rocks traversed, and in metamorphic pegmatites the order of replacement may be completely reversed within a few rods. Two characteristics, however, are common to all pegmatites - coarseness of texture and a notably uneven segregation of their constituent minerals.

The generally accepted belief is that all muscovite crystals large enough to yield sheet mica were formed by hydrothermal action of a mineralized solution on an original pegmatite consisting of potash, feldspar, and quartz. This belief in the replacement origin of large muscovite is borne out by (1) the frequent occurrence of the crystals in zones along the hanging wall or both walls of the pegmatite containing them or along cracks or planes of weakness, (2) the fact that the crystallization of the muscovite is not finer near the walls as would be expected through quicker cooling from contact with the walls if the crystals were deposited from the original injection, (3) the occasional occurrence of large mica books in the wall rock, and (4) the general similarity of the petrographical characteristics of pegmatites containing large muscovite to replacement veins and contact-metamorphic deposits. Anderson[8] states that evidences of replacement, especially the presence of albite, should serve as a guide in prospecting for mica and that those pegmatites that show little replacement should not be considered probable commercial sources of sheet mica. On the other hand, if a pegmatite presents ample evidence of hydrothermal action it probably contains large mica crystals and should be prospected along the channels of replacement. These channels rarely extend throughout the pegmatite; masses of the original graphic granite may constitute a large part of the deposit. Replacement usually is confined to zones along either or both walls of the pegmatite or to channels through the mass, which probably followed cracks or planes of weakness. In many places the replacing solutions have entered the wall rock, and large muscovite crystals may have been deposited there with all the other minerals occurring in the pegmatite proper.

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[6] Hess, Frank L., Pegmatites: Econ. Geol., vol. 28, August 1933, pp. 447-462.

[7] See footnote 6.

[8] Anderson, Alfred L., Genesis of the Mica Pegmatite Deposits of Latch County, Idaho: Econ. Geol., vol. 28, no. 1, p. 57.

W. T. Schaller of the United States Geological Survey, in a personal communication, points out that the formation of large muscovite usually followed closely and sometimes accompanied the albitization, which represents the first stage of the replacements, and that much replacement may have taken place after the muscovite was formed. However, extensive replacement is not always an indication of the plentiful occurrence of large muscovite crystals in a pegmatite.

PHLOGOPITE

Mineralogy

Phlogopite, more generally known as amber or magnesia mica, is second to muscovite in commercial importance but finds some special uses where it gives superior service. It occurs in monoclinic crystals which usually are six-sided prisms with irregular and tapering sides. The crystals range from minute particles to 4 feet in diameter, although such large specimens are rare. Phlogopite ranges from colorless and silvery white through shades of yellow, brown, and sometimes green to almost black. It has a pearly to submetallic luster on cleavage surfaces, with a coppery reflection which gave rise to its name, derived from the Greek, phlogopos, firelike.

Phlogopite has a highly eminent basal cleavage; the light-colored varieties can be split into thin, elastic folia as readily as muscovite. Dark phlogopites, however, cannot be split as easily as the light varieties, nor are they as good dielectrics.

The color of phlogopite often indicates its hardness, which ranges from 2.5 to 3; the darker kinds are notably harder than the light-colored ones. Variation of hardness with color is particularly notable in Madagascan phlogopites. According to the figures given here, phlogopite is harder than muscovite; but these figures apparently do not coincide with the experience gained from the use of these two micas in insulating commutator segments. For this use phlogopite is preferable because it wears down evenly with the copper and does not form projecting ridges. However, this more rapid wearing of phlogopite compared with muscovite is probably attributable to its greater friability rather than to any inferiority in hardness. Phlogopites, particularly light-colored varieties, are more resistant to heat than muscovites and will stand a temperature of 800° without appreciable dehydration, probably because they contain less water of crystallization.

Phlogopite in thin folia is transparent to translucent and often exhibits asterism in transmitted light due to regularly arranged inclusions. Asterism is particularly prominent in Canadian phlogopites. Its index of refraction ranges from 1.56 to 1.61. In sheets an eighth of an inch or more thick phlogopite is opaque. Its specific gravity is virtually the same as that of muscovite, ranging from 2.74 to 2.95. Unlike muscovite, however, it alters readily, losing its elasticity and assuming a high pearly luster, often with brownish spots as if from hydration of iron oxide. Like biotite, which approaches it closely in character and composition, it often alters to vermiculites. It is completely decomposed by sulphuric acid, leaving thin porous scales of silica.

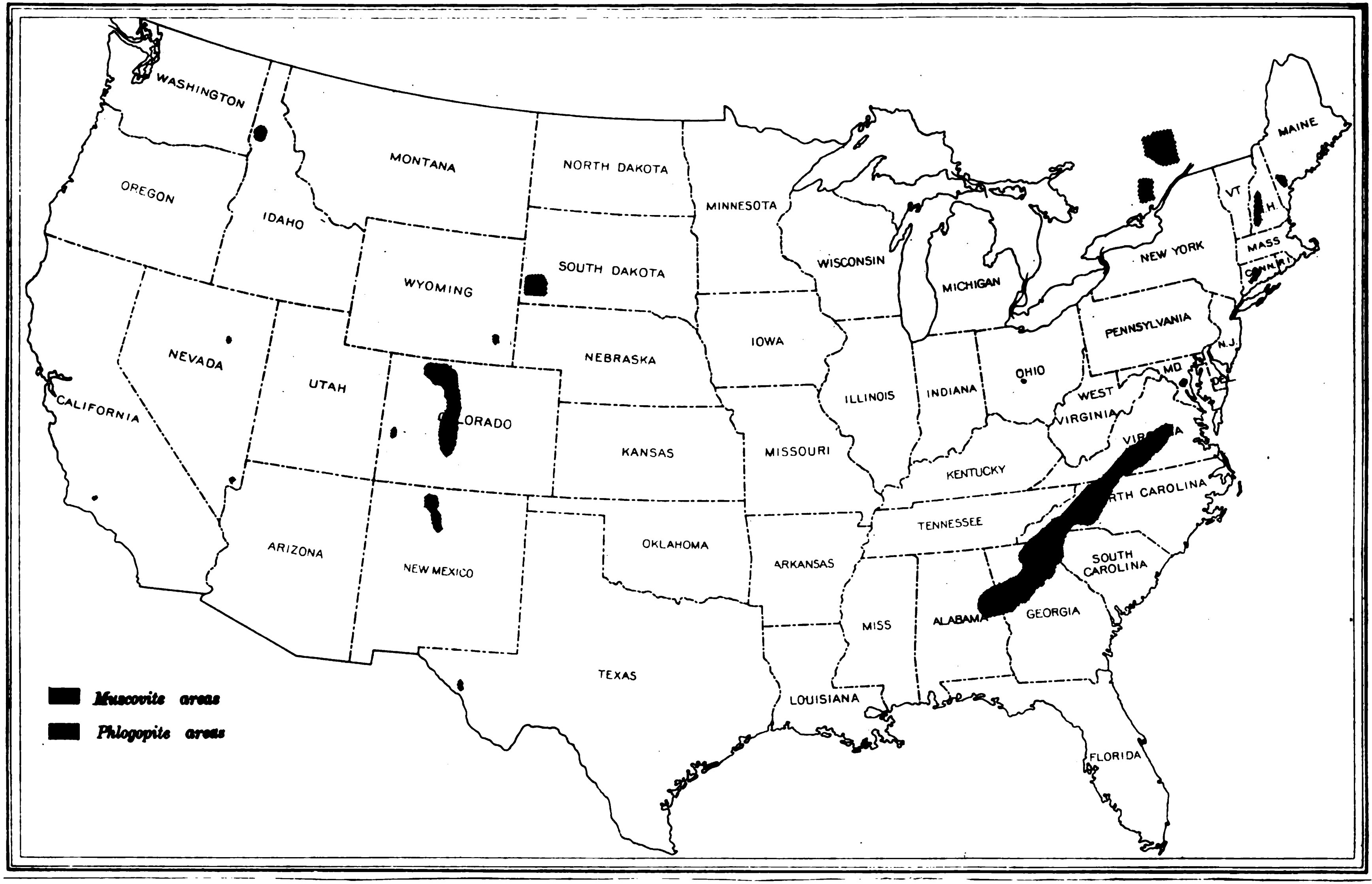

Figure 3.—Location of principal muscovite deposits of the United States and phlogopite deposits of Canada.

Schaller[9] states that the relations and crystallographic positions of the percussion figure, pressure figure, and parting planes are identical in muscovite and phlogopite. The optic axial planes in the two micas, however, are normal to each other.

The following table shows the composition of phlogopites from various sources.

TABLE 2.- Composition of phlogopite from various localities[1]

	Edwards, N.Y.	Burgess, Ontario	Ratnapura, Ceylon
SiO_2	40.64	39.66	42.26
Al_2O_3	14.11	17.00	15.64
MgO	27.97	26.49	27.23
K_2O	8.16	9.97	8.68
Fe_2O_3	2.28	.27	.23
FeO	.69	.20	1.52
BaO	2.54	.62	
Na_2O	1.16	.60	
TiO_2		.56	
F	.82	2.24	2.19
H_2O	3.21	2.99	2.91
	101.58	100.60	100.66

[1] Dana's System of Mineralogy, 1911, p. 633.

Occurrence

Phlogopite is a scarce mineral compared with muscovite, although it is quite abundant in some regions of contact metamorphism. However, so far as known, there are but few areas in the world in which commercial deposits of sheet phlogopite occur - the Provinces of Quebec and Ontario, Canada, eastern Madagascar, and Russia. In Canada the phlogopite deposits are confined to an area of about 1,200 square miles in Hull and Papineau Counties, Quebec, and approximately 900 square miles in Frontenac, Lanark, and Leeds Counties, Ontario. The location of these two areas is shown in figure 3.

In Madagascar phlogopite deposits have been found in 13 of the 14 Provinces of the island. However, almost the entire commercial output is confined to the southeastern Provinces of Ambrovombe, Betroke, and Fort Dauphin, which are listed in the order of their production.

Canada and Madagascar supply the world demand for sheet phlogopite, although the U.S.S.R. occasionally exports a few tons from deposits in the Mam region and in Karelia.

In the United States a small production of sheet phlogopite was made 30 to 50 years ago from 2 localities in Morris County and 2 in Warren County, N.J. The deposits in Morris County are (1) 4 miles west of Morristown near the Mendham road and (2) 1 mile south of Mendham; the deposits in Warren County are (1) 3 1/2 miles west of Washington and 1 mile north of Broadway on the south slope of Scotts Mountain and (2) 6 miles northeast of Phillipsburg and 3 miles north of Stewartsville. These deposits did not prove extensive or rich enough to justify continued mining.

Geologists hold diverse views as to the origin of deposits of sheet phlogopite, but the author accepts the supposition of Hess[10] that they were formed by pegmatitic solutions interjected into the easily soluble limestones, as observed petrographic relationships in all the deposits may be accounted for thus.

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[9] Schaller, W. T., U.S. Geological Survey Report D-269 to Scott Turner, Director, U.S. Bureau of Mines, Oct. 30, 1933.

[10] Hess, Frank L., Pegmatites: Econ. Geol., vol. 28, August 1933, p. 454.

USES OF MICA

The peculiar physical properties of mica - its high dielectric strength, perfect cleavage, flexibility, chemical and physical stability, transparency, and luster - make it serviceable in many industries and in many diversified uses. In some of these it is indispensable, as no satisfactory substitutes have been discovered.

Mica is the most valuable dielectric known; more than 90 percent of the world production of sheet mica is now consumed by the electrical industries. It is used as insulating rings, sleeves, and bushings and commutation-segment insulation in electric motors and generators and in condensers, electric-light bulbs and sockets, X-ray apparatus, spark plugs, fuses, heating elements of flatirons, toasters, percolators, and cigar lighters, induction coils, brush-holder studs, cable-joint insulation, grid rheostats, and dozens of other electrical devices. Films of both muscovite and phlogopite only one thousandth of an inch thick commonly withstand 5,000 volts without puncture when tested with spherical electrodes; muscovite free from bubbles and stains is ideal for use in electric condensers as it shows an exceedingly low power loss. The ability of mica to withstand high temperatures and corona discharge and the fact that it is not affected by oil or water add greatly to its desirability as an electric insulator.

The use of mica in the electrical industries was greatly enhanced by the invention in 1894 of built-up mica made of thin mica films or splittings cemented by shellac. Inasmuch as built-up mica can be made in sheets (plate mica) of almost any desired size and milled to uniform thicknesses, it is more easily fabricated than natural sheet mica. Further, it can be made into tubes of circular, triangular, or complex cross-section having multiple compartments, and with suitable binders it can be hot- and cold-molded into almost any desired shape.

Glyptal and other binders in place of shellac makes a more satisfactory product for certain uses. Inorganic binders are used principally in making built-up mica for heating elements. Mica paper and mica cloth in sheet form or as tape are made by bonding one or more layers of mica splittings on or between special papers and cloths. They are used for insulation in armature slots, commutator cores, magnets, etc., and for wrapping and winding coils and armatures.

Thin films of clear muscovite are irreplaceable in the manufacture of high-grade, small-capacity condensers such as are used in radio apparatus; the maintenance of the radio industry hinges in part upon ample supplies of suitable mica for making these condensers. Mica condensers are also used in telephone and telegraph systems.

Mica is substituted for porcelain in spark plugs designed to withstand unusual thermal and mechanical shock; the use of these plugs is favored in airplane motors where conditions are exceptionally severe. It is claimed that they stand up better in high-compression motors than porcelain plugs. In making mica plugs a sheet of so-called "cigarette mica", flexible enough to be rolled to diameters of 1/4 inch without cracking, is wrapped around the metal spindle of the plug, and mica washers are forced over it and assembled under pressure with a bonding compound. The outer surface of the compacted washers is then turned in a lathe to the desired shape, and the insulated spindle is ready for assembly.

For some dielectric uses amber mica or phlogopite is preferable to muscovite, as the light-colored varieties particularly will withstand a higher temperature. Further, amber splittings produce a more easily molded built-up mica, because they are less elastic than muscovite splittings. Phlogopite is also generally preferred for insulating commutator segments, because it wears down as fast as the copper. Muscovite placed flush with the circumference of the commutator would form hard ridges owing to its superior elasticity and wearing qualities, although it is not as hard as the more friable phlogopite.

In a discussion of the electrical uses of mica it should be pointed out that although amber mica is preferable for certain uses it can be replaced in almost every instance by muscovite with but slightly decreased efficiency. For example, one of the principal demands for amber mica is for the insulation of commutator segments, yet muscovite can be used with satisfactory results for this purpose by undercutting the mica to bring it below the surface of the copper. On the other hand, phlogopite cannot displace muscovite in many uses; it cannot be employed for condenser mica on account of its high power factor or for any purpose where high transparency is necessary. Specifications for dielectric mica are discussed in a later section.

The first commercial use of mica was for glazing, and clear muscovite has been used for this purpose for centuries. Because of its transparency, noninflammability, and resistance to shock, mica was used extensively during the latter half of the nineteenth century for stove windows and chimneys and shades for open-flame lights. Since the use of stoves for househeating has declined and gas and oil have been replaced largely by electricity for lighting the use of mica for glazing has decreased considerably, although there is still a fair demand for it as windows in gasoline, oil, and coal stoves, as chimneys for gasoline lanterns, shades for candle and other open-flame lights, nonbreakable spectacles for industrial use, windows in gas masks, and for glazing in metallurgical furnaces and kilns where it is subject to high temperatures. The use of built-up mica in torchiere chimneys, lamp shades, and panels is sufficient to warrant the manufacture of special art micas for these and other decorative purposes.

In addition to its uses for insulation and glazing, mica, because of its elasticity, makes excellent diaphragms for acoustic apparatus; at one time it was used extensively for this purpose in telephones and phonographs.

Grinding mica imparts to it broader fields of usefulness, depending on whether it is wet- or dry-ground. Wet-ground mica finds its principal use in the wall-paper trade where, with suitable vehicles, it is used as a decorative ink. It also forms a highly desirable filler for rubber but in general cannot compete in this field with talc, silica, asbestos, and other cheaper fillers. Wet-ground mica, however, is employed extensively in painting the water bags used in vulcanizing automobile tires, as it prevents sticking and gives the goods an excellent finish.

Dry-ground mica is used principally in the manufacture of rolled roofings and asphalt shingles to prevent adhesion of finished surfaces and to give the material better appearance and wearing qualities. Mica is particularly suited for this use because of its flakiness which prevents its absorption by the freshly made goods and because it is unaffected by the acid in the asphalt or by weathering. Roofing mica, whether derived from scrap or mica chist or recovered as a byproduct from kaolin mining, usually is graded to pass a 10- to 20-mesh screen. Larger sizes of dry-ground mica are used extensively for Christmas-tree snow and other decorative purposes. Finely ground mica is one of the principal constituents of many plastic wall finishes, rendering them particularly receptive to textural effects. Mica is also used for surfacing stucco and concrete to impart a stone finish and in the manufacture of artificial stone.

Ground mica is an excellent thermal and sound insulator; it is surprising that it has not been used more extensively for these purposes, just as heat-treated vermiculite is employed in walls and ceilings of buildings, wall board, pipe covering, etc. Mica, however, has been used to a limited extent as a thermal insulator in the heat treatment of steel.

Finely ground mica makes an excellent lubricant and is incorporated with greases for this purpose. Bonded with lead borate, it forms an electric insulator which can be molded at dull-red heat, can be drilled and machined, and has high mechanical and dielectric strength, making it suitable for aerial insulators, bases for radio tubes, etc.

SHEET-MICA DEPOSITS OF THE UNITED STATES

Geographical Distribution of Deposits

Although mica is an extremely common mineral, occurring in all 3 of the main classes of rocks (igneous, sedimentary, and metamorphic), crystals large enough to yield sheet mica are confined to 2 rocks. As already stated, large muscovite crystals occur only in replacement pegmatites, and the less common phlogopite or amber mica is found in pyroxenic rocks. Except for a few small deposits of phlogopite in northern New Jersey and New York, there are no known deposits of this mineral in the United States. A discussion of domestic sheet-mica resources is therefore confined to muscovite deposits or muscovite-bearing pegmatites.

Figure 3 shows the principal areas in the United States that contain such pegmatites It will be noted that the largest district extends from central Virginia through the western Carolinas, northern Georgia, and well into Alabama. This is by far the most important area and probably contains the largest reserves of commercial sheet mica. Second in importance is a relatively small region in southwestern New Hampshire, which has produced almost as much mica as the larger one just described. The larger comparative production in New Hampshire has been due to the fact that the pegmatites there are not covered to considerable depths with residual soil, as in the South, and can be examined and exploited more easily.

Next in importance as a source of sheet muscovite are the pegmatites of the Black Hills in southwest South Dakota. This area has contributed notable quantities of muscovite and has excellent possibilities for further development. A fourth area about the size of the New Hampshire district in northern New Mexico, has been developed to some extent but gives little evidence of becoming an important producer of sheet mica, as most of the muscovite from this district is "A", wedge, or tangle-sheet or so badly distorted and ruled as to make it fit only for scrap.

Small areas in southwestern Maine and central Connecticut contain a few deposits of good commercial grade. In Colorado a large area of mica-bearing pegmatites skirts the eastern slope of the Rockies and extends south from the Wyoming border to a little beyond the central part of the State. This region includes many scattered pegmatites, some of which have yielded small quantities of sheet muscovite, but as a whole the mica is of scrap quality. A small district in Latah County, northwestern Idaho, is a sporadic producer of small quantities of sheet muscovite of excellent quality, but because of distance from markets for scrap mica the development of mica mines in this area is seriously handicapped. Figure 3 shows small areas of muscovite pegmatites in Maryland, South Carolina, Texas, Wyoming, Nevada, and California; none of these States, however, has ever been an important producer of mica.

Description of Deposits, by States

Alabama

The mica-bearing pegmatites of Alabama are confined to the east central part of the State, the best deposits being in Randolph, Clay, and Tallapoosa Counties. Other deposits are in Lee and Coosa Counties. The mica-bearing area forms the southern end of the great

South Appalachian mica-pegmatite belt that extends northeast over 600 miles as far as central Virginia. The country rocks are crystalline schists, which extend northeast into Georgia and are probably the same as the Carolina gneiss farther north. The pegmatites cut the enclosing rocks at all angles and occur as lenses, sheets, and irregular masses, which in most instances have been kaolinized to a depth of 20 to 50 feet.

Colorado

Although Colorado has a large area of mica-bearing pegmatites no worth-while production of sheet mica has been made within the State. The mica is mostly A, wedge, and tangle-sheet suitable only for grinding.

Connecticut

Considerable scrap mica has been produced from time to time as a byproduct of feldspar mining in Middlesex, Hartford, New Haven, and Litchfield Counties, Conn. In general, mica from this State is A, wedge, tangle-sheet or ruled; only a few quarries have produced good sheet. Of recent years almost the entire sheet-mica output of the State has been derived from the Strickland quarry near Portland, Middlesex County.

Georgia

Mica-bearing pegmatites are found in twenty or more counties in Georgia, including Carroll, Cherokee, Elbert, Hall, Hart, Henry, Lumpkin, Meriwether, Monroe, Oconee, Paulding, Pickens, Rabun, Talbot, Troup, Union, and Upson. Most of them are in the Piedmont Plateau, but some occur in the rough mountainous section in the northeast corner of the State. As in North Carolina, the deposits are associated chiefly with Carolina and Roan gneisses, but in Pickens County a few of them are in later rocks, probably of Cambrian age. The rocks in the mica-bearing areas have been deeply weathered, and many of the pegmatites have been converted into "flukens" or decomposed pegmatitic material, the outcrops of which are marked by kaolin containing quartz boulders and clay-stained mica books scattered over the surface. Weathering often extends 50 to 75 feet beneath the surface, making it possible to mine the decomposed pegmatite with pick and shovel. Georgia mica is usually of good grade, although much of that near the surface is clay-stained. On the whole, the mica deposits of the State are virtually undeveloped, only a small amount of prospecting having been done on a few of the deposits. During the World War some of the flukens were mined to shallow depths with considerable profit. The author visited a dozen or more prospects in Cherokee and Upson Counties in which he observed good mica showings; he believes that the mica deposits of this State, under suitable market conditions, offer a promising field of development.

Maine

Most of the mica produced in Maine is obtained as a byproduct of feldspar mining from quarries in Androscoggin, Oxford, and Sagadahoc Counties in the southwestern part of the State. In the majority of the deposits the mica is fit only for scrap, but some excellent sheet has been obtained from several quarries in Oxford County, notably the Hibbs mine near Hebron and the Mt. Mica mine at Paris.

New Hampshire

The principal mica deposits of New Hampshire are in two groups in the southwestern part of the State, one of which is in southeastern Grafton County and extends into Sullivan County and the other is in the north central part of Cheshire County. A few small, sporadic occurrences are in Merrimac, Strafford, and Coos Counties, but these are of little importance. The deposits lie in rough, mountainous country at elevations of 800 to 3,000 feet. The larger group of mines, in Grafton County, is in a region of abandoned arms and neglected roads. The rocks are metamorphic schists and gneisses intruded by granite and pegmatite. The chists and gneisses, of great age, include biotite and muscovite schists interspersed with layers rich in quartz, black tourmaline, and garnet. The country is glaciated, and the pegmatites on the steeper slopes are more exposed than similar occurrences in the Southern States, although in the valleys they may be covered to great depths with glacial gravels.

The map of southern New Hampshire (fig. 4) shows the location of 54 of the principal mica mines and prospects of the State.

As a whole, the New Hampshire mines produce a larger percentage of white mica than those of North Carolina, although excellent ruby is common. Occasionally 2 and sometimes 3 distinct types of mica are found in the same pegmatite, as, for example, at the French mine of the New Hampshire Mica Co. at Alstead, where white, ruby, and green micas occur in horizons separated only by a few feet.

Wages for mine labor in New Hampshire have been considerably higher than those paid in the South and have handicapped mica mining in the State. Most of the mica deposits also are not easily accessible, and transportation of men and supplies is both expensive and difficult. The State, however, has many mines that have made good records as producers and have not been worked out and many promising prospects; these would warrant reopening and development in the event of higher prices for their product.

New Mexico

The principal mica deposits of New Mexico are west and southwest of Petaca in Rio Arriba County and in the Glorieta Mountains in San Miguel County.

Most of the deposits in Rio Arriba County lie in broken, mountainous country at elevations of 6,500 to 8,000 feet and 8 to 15 miles west of the Denver & Rio Grande Western narrow-gage tracks between Santa Fe, N. Mex., and Alamosa, Colo. The region is semi-arid at the lower elevations, but the mountains are more abundantly watered and are forested with pine. Petaca, the nearest settlement to most of the mines, is about 9 miles by road west of Servilleta, which serves as a shipping point for most of the mica produced in the district.

Among the mines and prospects examined in this district are the Cribbenville, Globe, American, Silver Ring, Fridlund, Monta Vista, Transcript, Moon (Nos. 1 and 2), Queen, Varos, Miller and Stiles, and Alamos, all in the vicinity of Petaca, and the Meda mine of the General Mica Co. near Ojo Caliente. In general, the mica from these properties is badly ruled and distorted and contains so much **A** mica and tangle-sheet that it is fit only for scrap. A small percentage, however, will yield good punch and small sizes of dimension sheet. As the deposits are considerable distances from a railroad and markets, the production of scrap mica has generally proved unprofitable.

The deposits in the Glorieta Mountains in San Miguel County are identical with those of Rio Arriba County in the character of their mica.

In the writer's opinion New Mexico cannot be considered a probable source of any important quantities of sheet mica larger than punch.

North Carolina

Sterrett[11] has grouped the mica deposits of North Carolina in three main belts - the Cowee-Black Mountain, the Blue Ridge, and the Piedmont. The Cowee-Black Mountain belt lies

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[11] Sterrett, Douglas B., Mica Deposits of the United States: U.S. Geol. Survey Bull. 740, 1923, 342 pp.

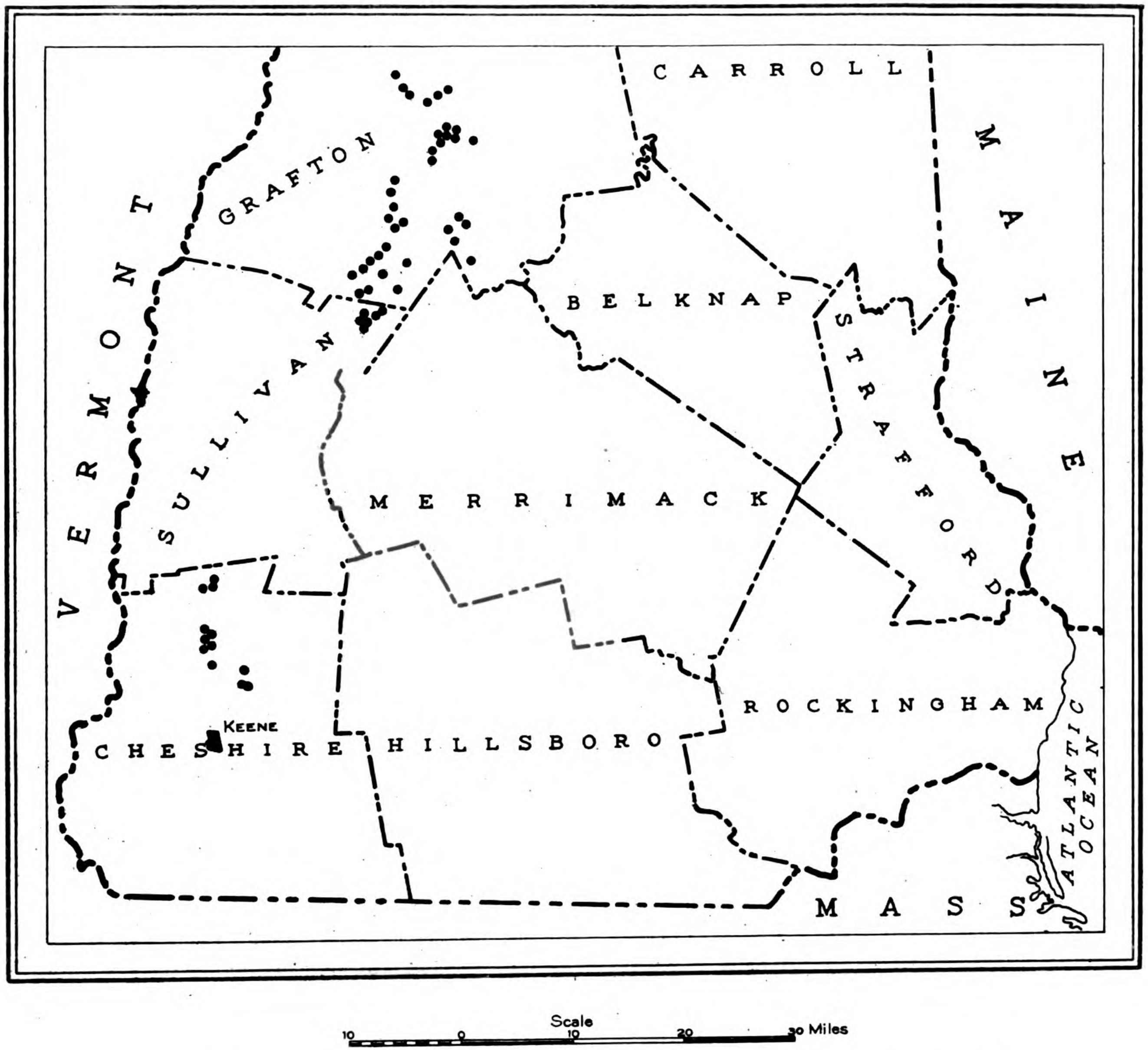

Figure 4.—Map of southern New Hampshire showing location of mica mines and prospects.

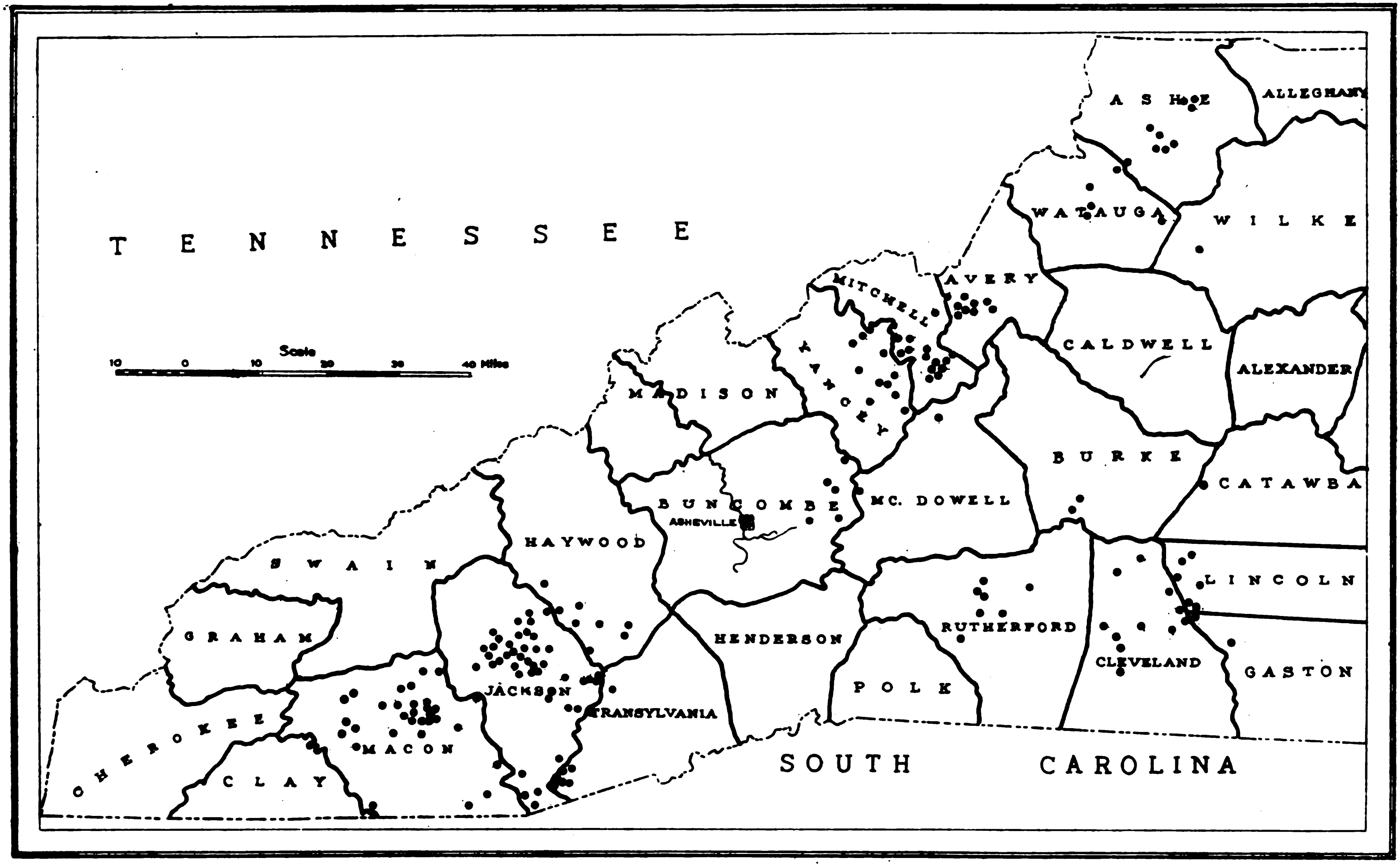

Figure 5.—Map of western North Carolina showing location of mica mines and prospects.

west of the Blue Ridge and roughly parallels the western border of the State, traversing Ashe, Watauga, Avery, Mitchell, Yancey, Buncombe, Haywood, Jackson, and Macon Counties. This is the most productive region in the State, and the mica from it is usually an excellent, clear ruby. The Blue Ridge belt follows the Blue Ridge Mountains through the State, extending on both sides of them but lying principally on their eastern slope, and embraces deposits in Jackson, Transylvania, McDowell, Mitchell, Yancey, Caldwell, and Wilkes Counties. In general, the mica from this belt is dark smoky to greenish brown and more or less specked. The Piedmont belt lies southeast of the Blue Ridge in the Piedmont Plateau and includes deposits in Burke, Cleveland, Rutherford, Gaston, Lincoln, Catawba, and Stokes Counties. The mica from this belt, particularly that mined in Cleveland, Lincoln, and Gaston Counties, is clear ruby of excellent quality, similar to that of the Cowee-Black Mountain belt.

The mica mines in the first two belts are at altitudes of 2,000 to 6,000 feet in the heart of the Appalachians, some on the rugged slopes of high mountains where the pegmatites are well-exposed and others on the gentle slopes of valleys where the pegmatites may be covered to a considerable depth with residual soil. In general, the location of deposits in these two belts facilitates mine drainage, an important factor, as the ground-water level in this region is not deep and the rainfall is heavy. In the Piedmont belt the mines are at slight elevation in a flat country, so that they cannot be drained by tunnels, and pumping is necessary.

The mica bearing pegmatites of the State occur in highly metamorphic rocks, probably all Archean, and consist largely of schists and gneisses, which have been altered greatly through extensive folding and faulting and great pressure. The principal formations in the mica regions are the Carolina and Roan gneisses interbanded and cut at all angles by pegmatites, locally mica-bearing.

Figure 5, a map of western North Carolina, shows the location of 166 mica mines and prospects.

South Dakota

The principal mica deposits of South Dakota are in the vicinity of Custer and Keystone in the southrn part of the Black Hills. The mines in this region have not been worked actively for nearly 20 years; from 1907 to 1911, the years of largest production, the annual output ranged from 500,000 to 1,500,000 pounds of rough sheet mica. The mines that were operated intensively during this period are now closed, as present costs are too high to warrant production. Recent prospecting, however, has disclosed several promising deposits, and the possibilities of obtaining considerable tonnages of sheet mica from this region would be excellent if prices were higher.

The Climax, White Star, St. Louis, Crown, New York, and Mica Wonder, all within a radius of 6 miles of Custer, are among the best-known mica properties. The Peerless and Hugo feldspar mines near Keystone produce considerable quantities of mica as a byproduct, but most of it is of scrap grade.

Virginia

The principal mica production of Virginia has been derived from deposits in Amelia, Goochland, and Hanover Counties; mica mines have also been worked in Amherst, Bedford, Charlotte, Franklin, Henry, Pittsylvania, and Prince Edward Counties. All these counties are in the Piedmont southeast of the Blue Ridge. The mica-bearing pegmatites occur largely in pre-Cambrian gneisses and schists and present no unusual features except in a few deposits where the association of amazonite, clevelandite, and oligoclase with brilliant chatoyance, spessarite, topaz, phenacite, microlite, columbite, monazite, and other rare-earth minerals makes the occurrences of special interest to the mineralogist.

Much of the sheet mica from Virginia is clay-stained, as most of the mines are shallow and the rocks enclosing the pegmatites have been decomposed to considerable depths. Otherwise it is of good quality, and much of the production has been utilized as stove mica.

MINING METHODS

General Features

The mica-mining industry in all producing countries is characterized by many small operations worked with a minimum of mechanical equipment and financial investment; the irregularity of both the pegmatites and the mica inclusions tends to discourage large, systematic operations. Domestic mica mines may be divided into three groups: (1) Small mines which are generally operated spasmodically, with little or no mechanical equipment; (2) medium-size mines which have been successful in a small way and have been increased in size and equipped with some machinery; and (3) large, well-equipped mines operated according to systematic mining methods.

The first group is operated in a most elementary way. The mine workings are very irregular and follow the mica occurrence in the pegmatite along rich streaks and from one pocket to another. As little waste rock as possible is taken out because of the difficulty in removing it through the small tunnels and openings. This method of mining is called "groundhogging" or "gophering."

Considerable good sheet mica is sometimes recovered from these small mines; but, broadly, they are uneconomic as they yield only a small percentage of the mica in the deposit and leave the workings in an unfavorable condition for reopening. They may be justified, however, in that they may produce some mica at a profit and they serve to prospect the deposit with the result that it may finally be developed into a profitable mine. Most small mines are usually operated as open-pit workings and are abandoned as soon as excavation reaches water level. Where the deposits are opened by a tunnel natural drainage is of great assistance.

If small operations disclose profitable quantities of mica, mechanical equipment may be purchased, mining systematized, and air compressors, drills, and pumps installed. An incline may be driven in the pegmatite to serve as a haulageway over which cars of mica and waste are brought to the surface. Any systematic stoping is generally impossible because of the irregularity of the deposits. The mica is recovered by driving simple breast stopes where it occurs most plentifully. Certain characteristics of the mica occurrence in pegmatites are often pronounced; for example, the mica may be confined largely to zones within 6 or 8 feet of the hanging wall, or rich pockets may be found associated only with large masses of quartz. This habit of occurrence may be a valuable aid in mining. Stulls are placed in the stopes to prevent slabbing from the walls, and timbering is done where necessary to hold the roof. Some flat-lying pegmatites have been worked by room-and-pillar methods.

In the third and much the smallest class of mines operations are well-organized. The ordinary practice is to sink a vertical shaft to cut the hanging wall at depth or to sink an inclined shaft along the foot wall. Drifts are run from this shaft into the pegmatite, and the mica-bearing rock is removed by breast or overhand stoping. A good example of such a well-planned mine is the Alexandria of the General Electric Co., at Alexandria, N.H. The workings of this mine are lighted by electricity, and considerable mica has been blocked out.

In mica mining care must be taken not to drill through or place powder charges in rich pockets of mica crystals; these pockets should be removed as far as possible by mining around them. An experienced drillman can readily detect mica under the drill by its peculiar resilience. Forty percent dynamite is commonly used. After a round of shots has been fired and the powder fumes cleared the mica is hand-picked from the muck and bagged before it is hoisted to the surface. If feldspar is recovered as a byproduct, all the muck may be hoisted to the surface, where the feldspar and any good mica overlooked underground is sorted out.

Considerable mica is recovered as a byproduct from feldspar mining. Most feldspar mines are usually worked as opencut quarries, although there are a few large underground operations. Some feldspar mines are splendidly equipped; one loads all broken rock with a gasoline shovel, crushes to size, and runs it over a picking belt, the waste being stacked mechanically. In these feldspar operations any mica recovered is thrown to one side and later sorted into block mica and scrap.

On the whole, mica mining, particularly if conducted by inexperienced operators, is a great financial risk; on account of the irregularity of the pegmatites and of the enclosed mica occurrences, rarely is a large-scale operation justified.

Summary of Production and Cost Data at Two Mines in North Carolina

Tables 3 to 8, inclusive, summarize the production and cost data at two mica properties North Carolina. Details of the operations have been presented in an earlier circular.[12]

TABLE 3.- Analysis of mining operations

Rock and spar mined and hoisted	tons	13,655
Rock mined and back-filled	do.	800
Total rock and spar mined	do.	14,455
Shots fired		5,113
Holes drilled, total length	feet	25,565
Per ton of rock broken	do.	1.75
Dynamite used (40 percent)	pounds	9,932
Average charge per hole	do.	1.94
Rock broken per pound of dynamite	tons	1.4
Block mica recovered (not including mine scrap)	do.	276
Recovered per ton of rock	pounds	38

TABLE 4.- Analysis of production

CLEAR MICA			
Size, inches	Pounds	Total value	Value per pound
8 by 10	100		
6 by 8	189		
4 by 6	690		
3 by 5	880		
3 by 4	659		
3 by 3	799		
2 by 3	1,886		
2 by 2	1,120		
1 1/2 by 2	1,068		
Total clear mica	7,391	$10,077.31	$1.35

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[12] Urban, H. M., Mica - Mining Methods, Costs, and Recoveries at No. 10 and No. 21 Mines of the Spruce Pine Mica Co., Spruce Pine, N.C.: Inf. Circ. 6616, Bureau of Mines, 1932, 16 pp.

TABLE 4.-Analysis of production - Continued

ELECTRICAL MICA

Size, inches	Pounds	Total value	Value per pound
8 by 10	373	....	....
6 by 8	941	....	....
4 by 6	3,577	....	....
3 by 5	3,888	....	....
3 by 4	2,721	....	....
2 by 3	5,602	....	....
2 by 2	14,285	....	....
Total electrical mica	33,681	$28,588.30	$0.85
Total sheet mica	41,072	38,665.61	0.94
Punch mica	156,238	7,761.85	.05
Factory scrap mica	354,776	3,547.76	.01
Total block mica	552,086	49,975.22	0.0905
Value of mine scrap mica and feldspar	....	6,987.14	....
Total value recovered	....	56,762.32	....

TABLE 5.- Costs

	Total	Per ton of rock mined	Per pound of block mica recovered
Mining labor	$24,455.34	$1.692	$0.0443
Mining supplies, including fuel	9,455.87	.654	.0171
Sheeting costs	5,854.81	.405	.0106
Total cost of mining and sheeting	39,766.02	2.751	0.0720

TABL 6.- Analysis of mining operations

Rock mined and hoisted	tons	4,530
Holes drilled, total length	feet	9,290
Per ton of rock broken	do.	2.05
Shots fired		2,066
Dynamite used (40 percent)	pounds	3,814
Average charge per hole	do.	1.84
Rock broken per pound of dynamite	tons	1.2
Block mica recovered	do.	107
Recovered per ton of rock	pounds	47

TABLE 7.- Analysis of production

Size, inches	Pounds	Total value	Value per pound
CLEAR MICA			
4 by 6	18		
3 by 5	95		
3 by 4	137		
3 by 3	343		
2 by 3	1,702		
2 by 2	1,641		
1 1/2 by 2	8,946		
Total clear mica	12,882	$5,391.60	$0.42
ELECTRICAL MICA			
3 by 5	6		
3 by 4	12		
3 by 3	27		
2 by 3	185		
2 by 2	447		
Total electrical mica	677	$251.80	$0.365
Total sheet mica	13,559	5,643.40	0.417
Punch mica	106,849	5,344.95	.05
Scrap mica	93,833	562.99	.006
Total block mica	214,241	11,551.34	0.0539

TABLE 8.- Costs

	Total	Per ton of rock mined	Per pound of block mica recovered
Mining labor	$6,519.07	$1.439	$0.0304
Mining supplies (including fuel)	1,673.05	.369	.0078
Sheeting costs	1,922.90	.424	.0090
Total cost of mining	$10,115.02	$2.232	$0.0472

Many interesting facts are revealed by comparative analysis of tables 3 and 6, which give production data for Nos. 10 and 21 mines, respectively.

By dividing the total value of the block mica recovered at the No. 10 mine by the tons of rock broken the value of the rock for mica alone is found to be $3.46 per ton. If the byproducts feldspar and mine scrap mica are included, the recoverable value of the rock is $3.93 per ton.

At No. 21 mine where there is no merchantable feldspar or mine scrap mica the recoverable value in the rock was $2.55 per ton. These values show that even when a pegmatite proves rich or at least rich enough to be worked at a profit the value per ton of rock considered as ore is low.

A similar analysis of tables 5 and 8 shows that the mining cost (labor and supplies per ton of rock was $2.35 and $1.81, respectively, at Nos. 10 and 21 mines; these figures when added to the sheeting costs give $2.75 and $2.23 per ton as the cost of mining and sheeting the block mica recovered.

The mining costs given above are high and plainly indicate the need of more efficient mining methods. It must be remembered, however, that there seems to be no way to prove mica values in advance of mining and that the initial investment required for the installation of machinery for low operating cost is not warranted except in unusual instances. Investment in more efficient equipment might be justified if a group of mines were operated which could be worked out one after the other and if each individual pegmatite were mined rapidly.

It will be noted that there is a great difference in both the size and quality of the mica produced by the two mines. At No. 10 mine 18 percent of the sheet mica was clear and 82 percent was electrical or stained mica. At No. 21 mine 95 percent was clear and only 5 percent was of electrical grade. At No. 10 mine 24 percent of the sheet mica was in the 3 by 5 inch class or larger, whereas at No. 21 mine less than 1 percent was in these larger classes. Finally, the average value of the block mica, in sheeted or prepared form, was $181 per ton at No. 10 mine, whereas at No. 21 mine it was $108 per ton.

The wide differences in production costs, yields, and the grades and classifications of mica recovered at these two mines are characteristic of mica mining the world over.

PREPARATION OF SHEET MICA FOR MARKET

Physical Characteristics of Book Mica

General Features

Mica as it comes from the mine is commonly in rough blocks ranging from a few inches to as much as 2 or 3 feet in maximum diameter. These blocks usually have ragged outlines and no plane boundaries, although they occasionally show well-developed crystal faces of hexangonal or rhombic prisms. Due to structural characteristics, inclusions, and color the rough crystals or books have certain physical peculiarities, to which miners and mica dealers apply descriptive terms. Thus, micas are usually characterized by their various structural imperfections as "ruled", "ribboned", "A", "hair-lined", "herringbone", "fishbone", "horsetail", "feather", "wedge", and "tangle-sheet." Inclusions have given rise to such terms as "black-spotted", "heavy-stained", "red-stained", "clay-stained", etc., while different-colored micas are variously known as "rum", "ruby", "white", "smoky", "green", "light amber", "silver-black", etc.

Structural Imperfections

The structural imperfections of rough mica crystals constitute the largest factor in determining the yield of sheet mica.

Parting planes often develop in the mica books from strains or movements in the enclosing rock, splitting the mica sheets into narrow strips or ribbons. This ruling is sometimes so extensive that the ribbons are almost hairlike and may render large mica crystals, otherwise of excellent quality, fit only for scrap.

In A mica two series of striations cross the sheets at an angle of about 60° with each other, forming a V. The third striation necessary to form the letter A is lacking, but this variety is nevertheless termed "A" mica. Sometimes the striations are evidently caused by wedge structure in the crystals and again by small ridges or folds in the sheets. If the striations are formed by wedging only that portion between the A lines is usable as sheet mica, but if they are caused by folding the mica may split across the folds and yield sheets of some value though not of first quality. Where the striations extend only in one direction the mica is known as "hair-line" mica.

Striations apparently identical with those of A mica but making angles of about 120° with each other and joining at a center line or spine give rise to a structure known as "fishbone", "herringbone", "horsetail", or "feather"; mica with such structure has no value other than for grinding.

The crystals of wedge mica, as the name implies, are wedge-shaped and are thicker on one side than on the other. This structure is common in A and fishbone mica and is due to unequal development in the width of the laminae forming the crystals, some extending the entire width of the block. The angle of the wedge may be as much as 30°.

"Tangle-sheet" is caused by the intergrowth of individual laminae, so that they split in some places but bind and tear in others; apparently sound crystals are thus made nearly valueless.

The mica books may be badly distorted, buckled, or corrugated, conditions probably produced by earth movements coincident with or subsequent to their crystallization. In fact, perfectly flat mica is rare; a slight waviness may be detected in even the better grades by touch or by visible differences in the reflection of light from their surfaces.

Impurities

The most common impurities in mica are oxides of iron, silica, and clay impregnating the crystals along their cleavage planes. The opportunity for the infiltration of these impurities was probably afforded by the opening of the cleavage planes through bending or distortion of the crystal by earth movements after their formation. Magnetite, perhaps the most prevalent inclusion, occurs as black and dark-brown spots and dendritic forms sometimes arranged in patterns having a definite relation to the crystal structure and again scattered irregularly through the sheets. The dark-brown color of many of these magnetite inclusions is due to the translucence of the mineral in thin films, but that the inclusions are magnetite can be proved by cutting them out and testing them with a magnet. Magnetite inclusions often alter to hematite or limonite, becoming red or brownish yellow. Striking color patterns are sometimes produced in this way; such micas are occasionally used for making lamp shades and other art objects.

In some localities thin sheets of silica are commonly found as inclusions between the mica laminae and interfere greatly with the sheeting of the mica. Some of these inclusions are heavy and occur in the form of wedges or lenses as much as a quarter of an inch thick.

Clay-staining is also a common impurity in mica and is due to the infiltration of muddy water between the laminae. It occurs only in mica coming from the zone of surface weathering and, of course, is most marked near the surface; it does not extend to the solid unweathered pegmatite. This impurity is often confined to certain planes in a crystal and may be removed by splitting.

Staining of any type renders mica unfit for use in electrical condensers, as it causes the mica to heat under an electric load. In most instances, however, the dielectric strength of mica moderately stained with metallic oxides does not appear to be lowered appreciably. Hence it is entirely satisfactory for most dielectric uses.

Crystals of garnet and black tourmaline are common inclusions in mica. Although usually small, garnets up to three quarters of an inch in diameter and tourmaline crystals several inches long have been found embedded in the sheets. Crystals of biotite also are prevalent in the muscovite, or vice versa, the two minerals generally having a common basal cleavage.

Such intergrowths, although interesting from the standpoint of the mineralogist, render the mica unfit for sheeting.

Color

The nomenclature describing the color of mica needs no explanation; sheets at least 1/16 inch or more in thickness are best for judging color, because thinner sheets are usually almost colorless. Dark mica is not as desirable as light, because it must be split thinner to give the transparency requisite for many purposes; moreover it is usually a poorer dielectric. Zonal variation in coloring usually disappears when the mica is split into thin films.

Bubbles

Mica for use in electrical condensers must be free from inclusions of air; air bubbles between the laminae are not unusual. If these are large and confined only to certain planes within the block they can be removed by splitting; in some instances, however, small bubbles are widely distributed between the folia, so that their removal is impossible. Sometimes these bubbles are microscopic and are so numerous as to form clouds in the mica. As already stated, mica containing bubbles is unsuited for use in condensers, but its dielectric strength does not appear to be adversely affected. Bubbles are probably caused by strains in the mica while in the ground, but many of them are certainly caused by rough handling in mining or in the course of preparing the mica for market.

General Features

The preparation of mica for market is necessarily a hand operation, as it requires the exercise of judgment to trim, split, cut, and properly grade mica. With the exception of the development of mechanical methods for producing mica splittings, which will be discussed later, it is probable that hand methods will be employed in the preparation of mica for an indefinite period and that labor will continue to be a most important element of cost.

All of the many forms in which completely manufactured mica is used are derived from two main classes of raw material - sheet and scrap. The preliminary preparation of mica for market consists primarily of separating it into these two classes.

Mica houses or trimming sheds, where the mica is stored and prepared for market, are provided at most of the larger mines. Generally, however, the small producers and many feldspar miners who recover mica as a byproduct sell their output either as it comes from the mine or roughly graded to firms who prepare it for the trade.

Cobbing and Rough Sorting

The rough crystals of mica as taken from the mine are of various shapes and sizes and are commonly referred to as "mine-run", "book", or "block" mica. This last term is unfortunate as it also applies to imported sheet mica. Mine-run mica is dirty and ordinarily has considerable rock adhering to it. The rough books are first cobbed, that is, all adhering rock is broken off with small hand hammers; the books are then rapped sharply to remove loose dirt. If the mica is exceptionally dirty it is sometimes passed over coarse screens. During the cobbing process the rough mica is examined carefully, and all books that are obviously so defective that they will yield no sheet mica are thrown into the scrap pile. In this way much badly ruled, fishbone, distorted, and otherwise defective mica is sorted out and requires no further handling.

Rifting

Cobbed mica is split into sheets about 1/16 inch thick or less by men and women known as "rifters." A knife having a stout, double-edged, 3-inch blade with a V-point is generally used in rifting; the edges of "tight" books are sometimes pounded with light hammers to loosen the laminae so that the rifting knife may be inserted. Considerable judgment and skill are required to split the blocks to the best advantage, that is, so that the imperfections will be removed as far as practicable and the maximum yield of high-grade mica obtained. Consequently, only thoroughly experienced rifters are employed. The products of the rifting operation are sheet stock, which goes to the trimmers, and punch or washer stock, which is commonly left with rough edges and is used for making disks, washers, and other punched forms and scrap.

Trimming

After the rifting process the ragged edges of the mica sheets are trimmed to remove the tangled ends of the laminae and thus facilitate further splitting. Trimmed sheet is known as "block", "uncut", or "unmanufactured" mica and is graded according to size and quality. Trimming may be done in a number of ways, but in general it is best accomplished with a sharp, thin-bladed knife held at a small angle with the cleavage of the sheet, so that a beveled-edged cut is produced. The beveled edge aids materially in further splitting, as the edges of each lamina project slightly beyond those of the one adjoining it, thus freeing them from entanglement. The bevel also presents a broader surface to the point of the splitting knife than a cut perpendicular to the cleavage and assists the splitter in gaging the relative thickness of the sheets to be split. Mica should always be bevel-trimmed in this way where further splitting is contemplated.

In India most mica, particularly that marketed through Calcutta, is bevel-trimmed with sickle-shaped knives and is known as "sickle-trimmed" or "India-trimmed." Sickle-trimmed mica is very irregular in shape and often has reentrant angles, but its preparation is generally excellent, all flaws and cracks being cut out. In this respect it is far superior to the usual run of domestic knife-trimmed mica, in which many imperfections often are allowed to remain. Because of its careful preparation Indian sickle-trimmed mica has won an enviable reputation in the trade and has given rise to the term "close-trimmed", in contradistinction to "rough-trimmed", from which only part of the imperfections have been removed. Mica from Madagascar, Guatemala, Argentina, and Brazil usually is sickle-trimmed. Another type of Calcutta trimming, known as "knife-trimmed", yields sheets with straight unbeveled edges in the shape of irregular polygons. Most African mica is trimmed in this way, although some is sickle-trimmed.

Mica from the Madras district in India is cut with shears into rough rectangles and is known as "Madras-cut" or "shear-trimmed" mica. The edges are not beveled but are cut normal to the cleavage. "Thumb-trimming" consists simply in breaking off with the fingers as much of the inferior material around the edges of the sheet as possible. It really accomplishes little but may be warranted in certain instances, particularly where the block mica is manufactured by the producer, as it saves the expense of more careful trimming.

In trimming mica domestic producers should bear in mind that sickle-trimming yields less waste and a larger weight of block than any other method. On the other hand, most mica cutters prefer the rectangular or Madras trimming; by purchasing the proper sizes they can predetermine waste with accuracy and can reduce it to the minimum. Trimming, of course, produces a large percentage of scrap mica.

GRADES

No other mineral product is so difficult to classify as mica or approaches it in the multiplicity of grades for size and quality, which vary widely with the country in which the mica is produced.

Domestic sheet muscovite is divided into three principal classes according to quality: (1) Clear, (2) slightly stained or spotted, and (3) heavily stained or spotted. The domestic classification with respect to size is as follows: The smallest size, designated as punch, must be large enough to yield a circle 1 1/2 inches in diameter if stained and 1 1/4 inches if clear. The next size is circle mica which yields disks up to 2 inches in diameter. Then follow the rectangular sizes: 1 1/2 by 2, 2 by 2, 2 by 3, 3 by 3, 3 by 4, 3 by 5, 4 by 6, 6 by 6, 6 by 8, 8 by 10 inches, and larger. Each size includes mica of the designated dimensions and all larger sizes to the next class. Thus, a sheet that would cut a rectangle 4 1/2 by 7 inches would be classed as 4 by 6.

Muscovite for glazing purposes, commonly known as stove mica, is classified according to quality as No. 1 stove or No. 2 stove. No. 1 stove must be clear and free from cracks and stains but may contain bubbles, whereas No. 2 stove may be spotted and stained to a limited extent.

Indian grading for size is based upon the area of usable mica corresponding to the areas shown in figure 6[13]; the general adoption of this chart for grading sheet mica and splittings is advocated by the American Society for Testing Materials.

In using the chart the mica to be graded is laid upon it with one corner at O and the maximum and minimum dimensions of the specimen extending along the lines OA and OB, respectively. The position of the mica is then shifted until its area completely covers the largest rectangle determined by a diagonal extending from O to or beyond one of the curves of the chart. The curve at the greatest distance from O, cut by the diagonal of the largest rectangular area in the mica, determines its grade number.

There are three sizes larger than those shown on the chart, which are known as special (48 to 60 square inches), extra special (60 to 80 square inches), and extra extra special (80 square inches or over). A small size, known as No. 7, having an area of less than 1 square inch has recently appeared on the market but is not generally recognized in the trade. For sizes larger than No. 4 the exact dimensions of the maximum rectangle are usually given, as a piece of mica covering 23 square inches is worth considerably more than one covering only 15 square inches, although they would both be classed as No. 2.

The following table shows the area of usable mica in the rectangles that can be cut from each of the various sizes of the Indian grading and the approximate corresponding sizes of the United States classification:

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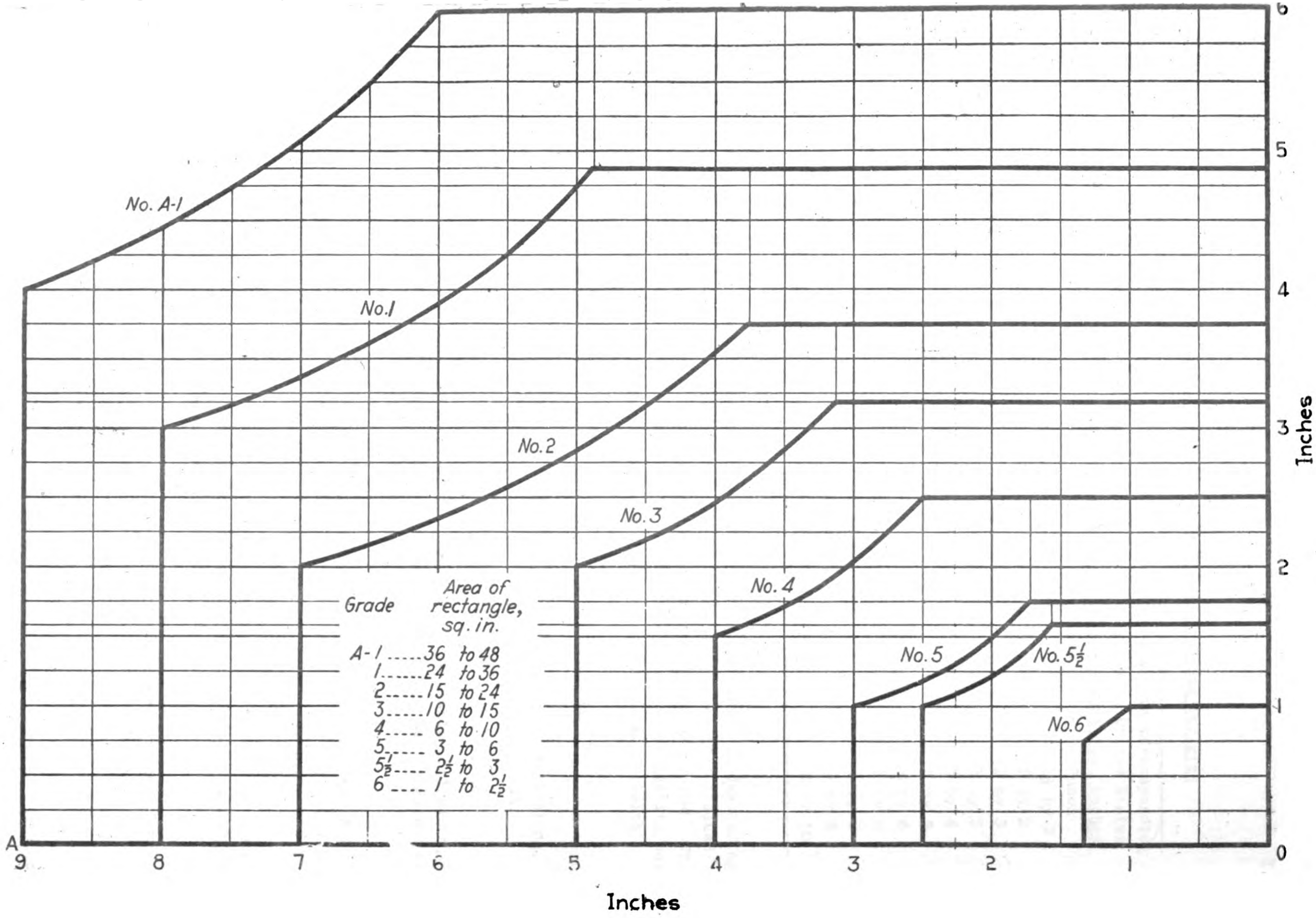
[13] American Society for Testing Materials, Tentative Method D351-33T.



Grade	Area of rectangle, sq. in.
A-1	36 to 48
1	24 to 36
2	15 to 24
3	10 to 15
4	6 to 10
5	3 to 6
5½	2½ to 3
6	1 to 2½

Figure 6.—Chart for India grading of mica.

Comparison of Indian and United States gradings for size

India grading	Area of usable mica based on rectangular sizes, square inches	Approximate corresponding sizes in United States classification, inches
6	1 to 2½	Punch
5½	2½ to 3	1½ by 2
5	3 to 6	2 by 2
4	6 to 10	(2 by 3 (3 by 3
3	10 to 15	3 by 4
2	15 to 24	3 by 5
1	24 to 36	4 by 6
A-1	36 to 48	5 by 8
Special	48 to 60	6 by 8
Extra special	60 to 80	8 by 8
Extra extra special	80 and over	8 by 10

Indian grading for quality comprises the nine following classes in descending order of value: 1, clear; 2, clear and slightly stained; 3, fair-stained; 4, good-stained; 5, stained; 6, heavy-stained; 7, black-spotted; 8, black-stained; and 9, badly stained. The American Society for Testing Materials in attempting to standardize grading for quality has combined the four poorer grades listed above and adopted the grading described herewith.

Quality	Description
Clear	Free of all mineral and vegetable inclusions, stains, air inclusions, waves or buckles. Hard transparent sheets.
Clear and slightly stained	Free of all mineral and vegetable inclusions, cracks, waves, and buckles but may contain slight stains and air inclusions.
Fair-stained	Free of mineral and vegetable inclusions and cracks, hard, and contains slight air inclusions and is slightly wavy.
Good-stained	Free of mineral inclusions and cracks but contains air inclusions, some vegetable inclusions, and may be somewhat wavy.
Stained	Free of mineral inclusions and cracks but may contain considerable clay and vegetable stains and may be more wavy and softer than the better qualities.
Black-stained or spotted	Same as stained but contains mineral inclusions.

The exact grading of mica for quality is extremely difficult, because it depends entirely upon personal interpretation of standards. As an aid to more uniform grading the American Society for Testing Materials proposes to prepare a set of master standards according to the above description from which photographs or transparent autochrome plates can be furnished.

Muscovite splittings are graded for size according to the Indian system, but the method of packing the splittings and their quality are also factors in determing grade. The usual grades recognized in the trade are: No. 6, cheap loose-packed; No. 6, medium loose-packed; No. 6, ordinary loose-packed; No. 6, second quality, loose-packed; No. 6, first quality, loose-packed; No. 5, special quality, loose-packed; No. 6, second quality, pan-packed; No. 6, first quality, pan-packed; No. 5, second quality, pan-packed; No. 5, first quality, pan-packed; No. 4 1/2, pan-packed; No. 6, book-packed; No. 5, second quality, book-packed; No. 5, first quality, book-packed; and No. 4 1/2, book-packed. Sizes larger than No. 4 are rare. In book-packing all splittings from one block are kept together in a book like a deck of cards. The individual splittings in the book are dusted with powdered mica to prevent them from sticking; in this form they are ideal for laying in the manufacture of plate or built-up mica. In pan-packing the splittings are laid radially in a circular pan usually 7 to 9 inches in diameter, depending on the size of the splittings, to form a thin, fairly coherent layer that can be used as a unit in the manufacture of mica plate. The grades of splittings vary widely and overlap. Hence they are usually sold under such trade names as "Walrus", "Rabbit", etc., the quality of common brands being fairly uniform and well known to mica buyers and consumers.

Sheet phlogopite or amber mica of Canadian origin is classified for size on the basis of its maximum rectangular dimensions, but the sizes differ from the United States standards. They are as follows: 2 by 3, 2 by 4, 3 by 5, 4 by 6, 5 by 8 inches, and larger. These sizes are either thumb- or knife-trimmed and are graded for quality as No. 1 (silver amber) and No. 2 (dark amber). Canadian amber splittings are graded for size as 1 by 1 undersize, 1 by 1, 1 by 2, and 1 by 3 inches and for quality, according to color

Madagascan mica, whether muscovite or phlogopite, is graded according to the following classification, which is enforced by the local bureau of mines.

Madagascan system of grading mica for size

Series	Grade	Size of rectangle, square inches
1	00	Over 48
1	0	36 to 48
1	1	24 to 36
2	2	15 to 24
2	3	10 to 15
2	4	6 to 10
3	5	3 to 6
3	6	1 to 3
3	All splittings.	
4	Smaller sheet than grade 6.	
4	Scrap and ground mica.	

Amber mica is graded for quality according to its hardness; this classification is easily made, as hardness conforms closely to color. Silver amber is graded as soft; brown amber, as medium; and amber-black to silver-black, as hard. Only the soft and medium amber micas are made into splittings, which at present are confined to No. 5 and No. 6 grades.

Madagascan muscovite is loosely graded for quality into clear and stained mica.

When it is remembered that in addition to the gradings already described a dozen other countries contribute mica to the world's supply and that none of them prepares or grades mica similarly, the great desirability of universal standards for grading becomes apparent. The adoption of such standards would temporarily inconvenience producers, brokers, and consumers but would be of great ultimate benefit to the mica industry.

SPECIFICATIONS

The specifications on which mica is purchased naturally vary according to its use. For electrical purposes the dielectric strength, power factor, resistance to heat, and sometimes flexibility are important properties. Specifications for dielectric strength differ widely for different electrical uses and with different consumers, but all mica free from cracks, pinholes, and certain types of staining has such a high dielectric strength that it rarely fails from electric puncture. Some types of staining seem to have little effect on the dielectric strength; in recent tests by the Bureau of Standards the dielectric strength of some stained micas in thicknesses of 5 mils and over was superior to that of perfectly clear micas. According to these same tests, which are discussed in detail in a later section of this report, bubbles in mica do not appear to affect its dielectric strength materially. A good dielectric mica, either stained or unstained, should withstand at least 1,000 volts per mil in thicknesses of 4 to 6 mils when tested with 2-inch plate electrodes.

Mica for use in electrical condensers should have a low power factor; otherwise it will heat excessively under an electric load. Hence, stained micas or those containing bubbles should not be employed for this purpose. A satisfactory condenser mica should have a power factor of 0.02 percent or less.

All good electrical muscovite is sufficiently resistant to heat for ordinary electrical uses and will withstand 500° to 600° C. without appreciable change. Therefore no specification for heat resistance is usually required if the mica is not to be subjected to higher temperatures. A soft, light-colored phlogopite, however, should be specified for use above 600° C., as these grades of phlogopite are more resistant to heat than muscovite. Phlogopite is generally specified for use in commutators because it wears at the same rate as the copper segments, thereby keeping the surface of the commutator smooth.

Flexibility is sometimes an important property of electrical mica; for example, a flexible mica is required in wrapping the spindles of spark plugs where thin sheets have to be rolled to small diameters. A usual specification for so-called "cigarette" mica is that a sheet 1 mil thick can be rolled into a cylinder 1/4 inch in diameter without cracking.

Consumers often specify India mica partly because of the erroneous belief that India mica is of superior quality and partly because of the poor preparation of domestic mica which otherwise is in every way comparable to the Indian product.

MACHINE-SPLITTING OF MICA

The preparation of mica splittings by hand is slow and expensive, and the labor involved is the principal item of the total cost. If splittings could be produced in quantity by machine, great savings obviously could be effected. Several companies in this country have experimented recently with various processes of machine-splitting; one produced considerable quantities of amber splittings. The principle employed in this particular instance is simple - the mica books are bent to make the folia slip on each other. The mica, preferably in books less than 4 square inches in area and 3/32 inch thick, is first heated to 300° to 400° C. and then suddenly cooled in water. This treatment tends to loosen the individual laminae.

The mica from the cooling vats is placed in coarse-mesh bags, and most of the water is extracted by ordinary centrifugal dryers. The remaining water is removed in drying ovens. The mica is then ready for the splitting machine, which consists primarily of two superimposed belts moving in the same direction in contact with each other. The mica is fed between these two belts, which carry it over a roller and then alternately under and over a series of stationary rods with faces that present increasingly sharp angles. This process bends the mica books back and forth through greater and greater angles until they are finally bent through almost 90°. In this way the individual sheets of a mica book are forced to slide on each other exactly like the leaves of a magazine when bent.

This treatment bends the mica books three times in opposite directions; the conveyor belt then discharges them into the boot of an elevator, which carries them to a trommel having a screen of about 1/2-inch mesh. The trommel separates the loosened books into individual leaves or splittings and at the same time removes all fine mica as undersize. The oversize, consisting of pieces ranging from those well split to those unsplit, drops from the end of the trommel for about 10 feet and passes in front of a perforated suction roller over which runs a coarse-mesh wire belt. The suction in the roller is so regulated that the lighter well-split mica is deflected in its fall and sucked against the wire belt, while the heavier, less completely separated pieces pass by and are returned to the splitting belts for further treatment. This method of sorting the well-split and poorly split mica is surprisingly efficient. Simultaneously with the sorting, the suction roller and wire belt also act as a laying machine which spreads the mica evenly, ready for spraying with binder.

The author saw this process in operation, and although it was not then perfected it worked fairly well. Three persons handled the entire process - one fed the mica heater, one attended to the drying, and one operated the splitting machine. The labor cost of producing splittings probably did not exceed 1 cent a pound; it is evident that the cost of this process, including overhead, is much less than that of hand-splitting. The waste was about 50 percent when amber mica recovered from old mine dumps was treated. Weathered Canadian phlogopite can unquestionably be handled successfully by the process described, but whether freshly mined phlogopite or muscovite can be treated equally well is a question.

For several years small quantities of muscovite splittings have been made regularly by machine, but as production has not increased it appears that such methods enjoy no advantages as to cost over the hand method of splitting. However, machine-made splittings in general are reported to be more uniform in thickness than all but the best grades of the hand-made product and make superior grades of built-up mica.

It is hoped that continued efforts to develop economical processes for machine-splitting will be successful in order to relieve the domestic industry from its almost absolute dependence on imported splittings. In this connection it should be pointed out that machines can split only the same grades of mica that can be split by hand and that they cannot make splittings of tangle-sheet or other scrap micas.

MICA GRINDING

Mica is ground by either wet or dry processes, depending on the uses for which it is intended and on its physical character.

Wet-ground mica is employed principally in the wall-paper and rubber industries where a high luster and ability to mix smoothly with liquid vehicles are required. Wet-grinding under carefully regulated conditions is the only process known for reducing mica to fine sizes without destroying its sheen and slip. Freedom from biotite, heavy staining with clay or iron oxides, and excessive quantities of gritty minerals is a requisite for wet-ground mica for the wall-paper trade. Color is also important, as some micas do not produce as white a product as others. If wet-ground mica is intended for the rubber trade color and freedom from dark specks is generally unimportant; wet-ground biotite and chlorite are sometimes sold to this industry. Wet-ground mica should have a high metallic luster, should feel slippery and be free from grit, and should mix smoothly with liquid vehicles.

The following screen analyses show the fineness of two standard brands of wet-ground mica for use in decorating wall paper. The weight per cubic foot of the ground mica is also given.

Screen analyses of wet-ground mica

Through	Brand 1, percent	Brand 2, percent
60-mesh	100	100
80-mesh	99.5	99.9
100-mesh	99.0	99.7
150-mesh	98.2	97.5
200-mesh	97.2	94.0
325-mesh	87.7	76.3
Weight per cubic foot, pounds	14	15.5

Dry-grinding processes subject the mica to such violent abrasion that the edges of the individual particles are torn and hackly; in fine sizes (under 40-mesh) the smooth surfaces of the flakes are largely if not entirely destroyed. Mica ground dry to 100-mesh size looks like flour, has but little slip, and is difficult to incorporate in smooth mixtures with liquids. This property of not mixing well with liquids gives the pleasing textural effects obtained with wall finishes containing a high percentage of dry-ground mica ranging in size from 70- to 220-mesh.

Dry-ground mica is used chiefly to prevent adhesion between surfaces of asphalt shingles and rolled roofing and to impart wearing qualities and a pleasing finish to these products. For this purpose 10- to 40-mesh size weighing 14 to 20 pounds per cubic foot is usually specified. A light-weight mica is desired by the roofing trade, as it has a greater covering power per unit of weight than a heavier product. However, in an effort to obtain large coverage the appearance of the articles is sometimes sacrificed, as the flakes of an unusually light mica are so thin that the dark background of the material is too readily seen through them. Consequently they do not produce as bright and pleasing a finish as thicker and heavier flakes. Coarser sizes of dry-ground mica (4- to 10-mesh) are used for Christmas-tree snow and similar decorative purposes, but the consumption of these sizes is comparatively small.

Wet-Grinding

Wet-grinding is done in chaser mills consisting of annular steel or wooden pans up to 10 feet in diameter and 40 inches in depth, in which wooden rollers rotating on horizontal arms revolve about a central shaft. The bottoms of the pans are lined with and the rollers made of end-grain wooden blocks, oak, maple, and black gum being preferred. The mills may be equipped with 2, 3, or 4 rollers ranging in diameter from 30 to 40 inches. The roller faces are generally 20 to 24 inches wide, and the rollers are so arranged that they can be raised or lowered according to the depth of charge in the mill. Steel plows following each roller turn the charge to present new material to the grinding action of the succeeding roller and keep the mica in the path of the rollers. The mills usually operate at 20 to 40 r.p.m., varying with the dimensions of the mill and the weight of the charge, and consume about 20 hp. Complete grinding of 1-ton charge of mica requires 4 to 8 hours; the time varies with the physical character of the mica and speed of the mill. The mica, unless it is clean shop scrap, is washed thoroughly to remove fine rock and dirt before it is ground. Grinding is started without water, but as the mica breaks up water is added gradually to form a stiff paste and the grinding is continued under carefully regulated conditions until the charge is completely ground. The friction generated in the charge produces so much heat that the water actually boils, and care must be taken to prevent the mica from becoming too dry and "burning." The water content of the charge must therefore be watched carefully. If too much water is used proper grinding is precluded, and if too little is used the mica will burn and lose its sheen.

The ground charge is sluiced from the mill into wooden sand boxes or launders, where the gritty impurities and coarse mica settle. The overflow carries the fine mica to wooden vats, where it is allowed to settle and the clear water is siphoned off. The mica sludge is then transferred direct to steam tables, or it may be filter-pressed before drying. The dried mica is run over a vibrating scalper screen, usually of about 60- or 80-mesh, to remove heavy particles that would injure the fine silk cloths of the bolting machines on which it is sized. The bolting machines are similar to those employed in bolting flour; replacement of the expensive silk cloths is a large item in the cost of screening mica. The mica is bolted through 160- to 300-mesh cloths according to specifications, and the oversize is returned to the mills for regrinding. Normally 80 to 85 percent of the mica is recovered as a finished product. In all of the operations great care is exercised to keep the mica clean and free from oil and iron stain.

A grinding plant with 3 mills makes about 2 tons of finished product in a 10-hour day. Seven men are employed: 1 fireman, 1 millman, 1 vatman, 1 filter-press man, 2 driermen, and 1 screen and bag man. About 85 hp. is required to operate the mills, pumps, elevators, and screens in such a plant, and approximately 1/2 ton of coal is burned to dry each ton of finished product.

Dry-Grinding

Dry-grinding of scrap mica is done almost exclusively in high-speed hammer mills or pulverizers of the cage-disintegrator type equipped with screens or air separators. For satisfactory results the feed to these mills must be dry; rotary dryers are commonly used to remove excessive moisture. The discharge from the mill screens is generally elevated to multiple-deck vibrating screens which produce the sizes required. Dry-grinding of mica presents no particular problems, and the process and machinery used are generally a matter of the personal preference of the mill owner. In some installations rod mills have been used successfully for dry-grinding mica. One Canadian mill employs a grinder in which the mica is disintegrated between two horizontal steel disks, the opposing surfaces of which are provided with rows of teeth. The lower plate is stationary, while the upper plate rotates at high speed. The fine mica is discharged through an opening in the side of the machine and is conveyed to the sizing screens.

PHYSICAL PROPERTIES OF DOMESTIC AND FOREIGN MICAS

General Considerations

The suitability of domestic sheet muscovite for certain uses has been a point of controversy among producers, importers, and consumers of mica for years. Claims have been made that the domestic product is inferior to some foreign muscovites, particularly Indian muscovite, as a dielectric; that it heats excessively when used in condensers; and that it will not withstand as high a temperature as Indian mica without decomposition. In fact, many consumers believe that Indian mica possesses qualities not inherent in the muscovites of the United States or other countries. On the other hand, domestic producers assert that high-grade domestic sheet muscovite equals and for some uses surpasses the best Indian product. They point out that even mica experts cannot distinguish Indian mica from comparable domestic mica when similarly trimmed and that contracts specifying the Indian product are often filled wholly or in part by domestic mica without complaint from the consumer. The preference of many consumers for the Indian product is presumably based on substantial grounds, but inasmuch as Indian muscovite is virtually identical in chemical composition and mode of occurrence with that from many other countries it seems unreasonable that its physical characteristics are markedly different.

Staining and air bubbles are normally considered to impair the dielectric strength of mica greatly, but the writer's attention has been directed to so many instances in which this theory appears untrue that it seemed desirable to determine, if possible, the effect of these imperfections.

Because the questions involved are of interest to every consumer of sheet muscovite and of vital importance to many of the essential industries of the United States, should supplies of foreign mica be shut off, the author sought the aid of the National Bureau of Standards, after a search of the literature revealed a surprising lack of reliable data on the subject, to determine the differences in electrical properties, if any, in micas from various geographical sources and the effect of bubbles and stains on dielectric strength.

The Bureau of Standards gave its immediate and hearty cooperation. Not only were technicians assigned to plan and perform the tests involved, but a considerable sum was spent for special apparatus and equipment. Comparative tests were made on several hundred samples of mica representative of the major sources of the world's supply to determine their dielectric constant, power factor, dielectric strength, and physical changes on heating to elevated temperatures. Further tests were made to ascertain how stains and air bubbles in sheet mica affect its electrical properties.

Summary of Results

The results of these tests showed that there is no marked distinction between the electrical properties of micas of different geographical origin. In other words, comparable grades of mica, irrespective of source, are virtually identical as to dielectric strength and power factor. Indian muscovite certainly has no better electrical properties than comparable grades of domestic muscovite, but the preference of many users for the Indian product is apparently justified by its superior grading and better preparation for market. On the other hand, the results of the tests show that domestic muscovite generally has a slightly higher dielectric strength than Indian muscovite and is more resistant to physical changes on heating to temperatures above 600° C. The writer believes that these properties are due to the fact that the domestic mica is usually harder than the Indian product and possibly contains less water of crystallization. For most electrical uses, however, these slight advantages of domestic muscovite are more than offset by its generally poor preparation for market.

The tests also showed that heavy staining and bubbles in muscovite increase its power factor enormously and render it unfit for use in condensers. Contrary to general belief, however, moderate staining with metallic oxides apparently does not lower the dielectric strength materially. In many instances heavily stained mica in which the staining was accompanied by air bubbles showed a higher dielectric strength when tested with spherical electrodes than the best grades of clear mica. Furthermore, the presence of air bubbles does not appear to lower the dielectric strength of mica; a large majority of the micas containing bubbles, particularly those containing clouds of microscopic bubbles, showed appreciably higher dielectric strengths when tested with spherical electrodes than those free from these imperfections. The mechanism of dielectric break-down is not understood well enough to justify the writer in attempting to explain these seeming anomolies; it may be mentioned, however, that extremely thin films or layers of gas are in general good dielectrics, as they are too thin to allow normal ionization.

As already stated, the results of the heating tests at elevated temperatures show that domestic muscovite has a higher resistance to temperatures above 600° C. than Indian muscovite. They also show the marked superiority of the soft, light-colored phlogopites over muscovites in heat resistance.

Physical properties of mica, such as its hardness, resistance to abrasion, and ability to be rolled into tubes of small diameter without cracking, which are important in many of its specialized uses, were not studied because of limited funds. It is well known, however, that these properties sometimes vary widely in mica from the same mine and that often micas from two mines in the same district may show more variation in hardness, color, flexibility, flatness, and cleavability than those from two different countries.

Reports of the tests furnished the United States Bureau of Mines by the National Bureau of Standards have been condensed and rearranged and are presented here. Some additional data, however, have been taken from Research Paper 346,[14] which describes the methods used in the electrical tests in more detail than given here. Due acknowledgments are made to the Bureau of Standards and to F. B. Silsbee, H. B. Lewis, E. L. Hall, and F. R. Caldwell, under whose direction the tests were conducted.

Measurement of Dielectric Strength of Domestic and Foreign Micas[15]

The investigation described here was undertaken by the Bureau of Standards at the request of the Bureau of Mines to determine the differences, if any, between the dielectric strength of foreign and domestic micas and the effect of staining and air bubbles on its electrical insulating value. Fifty-five samples of sheet mica, representing the major sources of the world's supply, were available for test. Of these 36 were from domestic and 19 from foreign sources.

As there is no generally accepted standard procedure for determining the dielectric strength of mica, the experimental conditions under which the tests were conducted will be specified. The size and shape of the electrodes used, as well as the nature of the surrounding medium, are of primary importance in determining the nature of the electric field to which the specimen is subjected. For testing sheet material the specifications of the American Society for Testing Materials require 2-inch flat electrodes with rounded edges, immersed in oil to prevent corona and flash-over. Some investigators have used flat electrodes embedded in porcelain and surrounded by a film of aniline to exclude air, while others have used spherical electrodes. In a preliminary investigation at the Bureau of Standards the results obtained with American Society for Testing Materials electrodes under castor oil, with 1/4-inch flat electrodes surrounded by soft rubber pads and with 1-inch spheres under light mineral oil, differed widely. Mica that had been soaked in oil for 4 days showed no appreciable change in break-down voltage. Likewise, prolonged soaking in water produced no measurable effect when all surface moisture was removed before testing.

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[14] Lewis, A. B., Hall, E. L., and Caldwell, Frank R., Some Electrical Properties of Foreign and Domestic Micas and the Effect of Elevated Temperatures on Micas: National Bureau of Standards Jour. of Res., vol. 7, August 1931.

[15] The tests described were conducted by A. B. Lewis under the supervision of F. B. Silsbee, National Bureau of Standards.

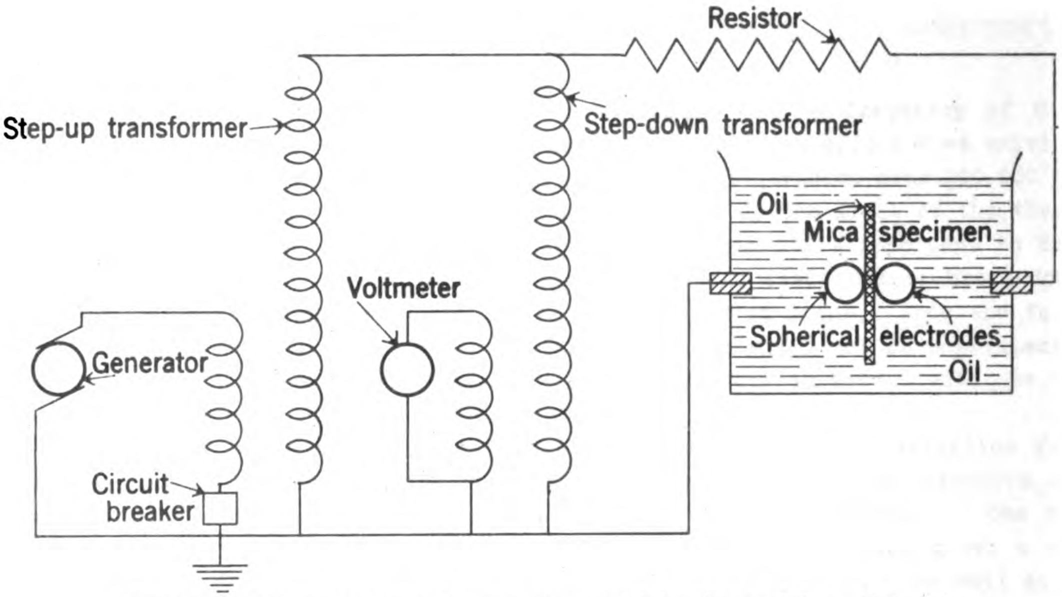

Figure 7.—Arrangement of apparatus used in determining dielectric strength of mica.

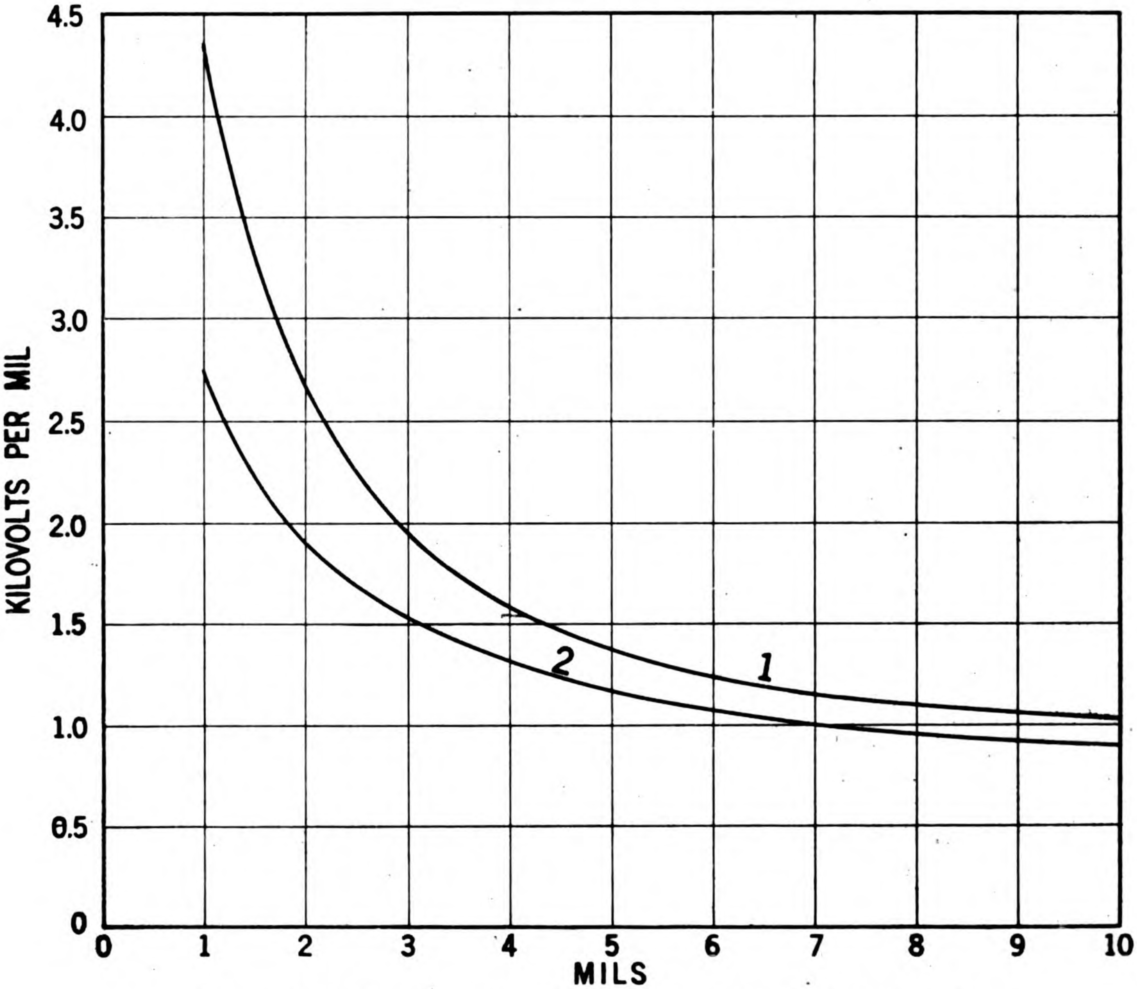

Figure 8.—Dielectric strength of a badly stained domestic mica as determined with spherical (curve 1) and with plate (curve 2) electrodes.

At ordinary power frequencies the effect of change in the frequency of the applied voltage upon the break-down voltage is probably slight. Such an effect does exist, however; Grünwald[16] found that the dielectric strength of mica at frequencies near 200,000 cycles per second is appreciably lower than at 50 cycles per second. In the light of the theories that break-down is due to formation of hot spots or hot filaments it is important to specify the time interval during which the specimen is in the electric field before break-down occurs or the rate at which the voltage is raised to the break-down point. From the foregoing it is apparent that the dielectric strengths obtained under a given set of experimental conditions, while comparable among themselves, are not necessarily in accord with the values obtained under an entirely different set of conditions.

The large number of samples to be tested made simplicity of construction and ease of manipulation important factors in the selection of apparatus. It was therefore decided to use as electrodes 1-inch spheres immersed in light mineral oil (Marcol). One sphere was connected to one high-voltage terminal of a step-up transformer which gives a maximum of 25,000 volts and is rated at 3 kv. The other side of the transformer, as well as the other sphere, was grounded. This transformer was supplied with 60-cycle voltage of virtually sine wave form. The high voltage was measured by a step-down transformer of the same ratio and rating as the supply transformer. The high-voltage coils of this standard transformer were placed in parallel with the sphere gap and the high-voltage coils of the supply transformer, and the resulting voltage was read from a voltmeter across the secondary terminals of the standard transformer. The voltage reading could be made within an accuracy of about 1 percent. This reading multiplied by the ratio of transformation of the standard transformer, which is accurately known, gives the total voltage across the specimen under test. The thickness measurements were made with a dial micrometer. A resistor of approximately 20,000 ohms was placed in series with the test specimen to prevent excessive surges in the line at the instant of break-down. Figure 7 illustrates the electric circuit used and the arrangement of the apparatus.

The foreign micas available for test were already graded. The domestic micas were graded at the Bureau of Standards. After the tests were completed all specimens were graded by the Asheville Mica Co., Biltmore, N. C.; these gradings exactly checked the original gradings. Three representative samples were taken from each lot of mica and split to thicknesses of approximately 1, 5, and 9 mils, respectively. By careful splitting it was possible to obtain specimens of sufficient size for testing in which the thickness was constant to within 0.1 or 0.2 mil over the entire surface. The uneven surface of the amber micas (phlogopites) made this measurement uncertain to about 0.5 mil on the thicker pieces.

Each specimen was inserted between the spheres and an initial low voltage applied. The voltage was then raised continuously at a rate of approximately 800 volts per second until break-down occurred. Five punctures were made on each thickness; the mean of these five observations was taken as the break-down voltage at that thickness. The average percentage deviation from the mean for each thickness was computed. The mean of the average deviations for the three thicknesses tested was thus obtained for each lot of mica. This number is the "average deviation" shown in table 9 and gives a rough idea of the reproducibility of the data and the uniformity of the mica. The three values of break-down voltage obtained for each lot were plotted against thickness, and a smooth curve was drawn through the resulting points. From this curve was read the break-down voltage (effective volts) corresponding to exactly 1, 5, and 9 mils. These are the values of break-down voltage given in table 9.

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[16] Grünwald, F., Arch. Elektrotecnnik, vol. 12, p. 27, 1923-24.

TABLE 9.- Dielectric strength of domestic and foreign micas

DOMESTIC MUSCOVITES

Source	Classification	Average break-down voltage, kilovolts			Average deviation, percent
		1 mil	5 mils	9 mils	
Connecticut:					
Middlesex County:					
Strickland quarry, Portland	Clear, honey color	7.0	12.4	16.4	9
Georgia:					
Malden mine	Clear ruby, first quality.	5.3	10.3	11.4	7
Idaho:					
Latah County:					
Mine unknown	Black-spotted ruby	5.3	8.0	11.4	8
Maine:					
Oxford County:					
Hibbs quarry, Hebron	Clear ruby, wavy	8.3	9.1	12.4	4
Merrill mine, Paris	Clear light ruby, wavy.	4.8	9.8	11.9	3
Mine unknown	Clear light ruby	4.9	9.2	12.0	6
New Hampshire:					
Cheshire County:					
Golding-Keene quarry, Alstead	Stained ruby, wavy	6.6	8.8	13.2	9
New Hampshire Mica Co., Alstead	Clear pale green	5.8	9.4	12.9	7
Do.	Clear ruby	5.8	9.9	13.8	4
Do.	Light smoked ruby	4.7	10.1	15.4	7
North Carolina:					
Avery County:					
Huston Rock mine	Light black-spotted	5.7	10.3	15.8	6
Johnson mine	Clear ruby	5.2	9.6	11.6	3
Porter mine	Clear ruby	5.8	9.8	12.6	3
Elk mine	Clear light ruby	3.3	11.1	11.9	5
Cleveland County:					
Mine unknown	Clear ruby, first quality.	4.5	10.4	14.2	13
Gaston County:					
Mine unknown	Clear ruby	6.0	10.1	14.6	6
Haywood County:					
Big Ridge mine	do.	6.3	12.8	17.4	7
Mitchell County:					
Hawk mine	do.	8.5	11.3	15.5	4
English Knob mine	Clear dark green	6.2	8.9	12.2	4
Hoot Owl mine	Black-spotted	3.8	9.2	14.6	7
Deer Park mine	Clear dark green	5.5	10.0	12.4	6
Abernathy mine	Clear ruby	5.1	11.4	14.2	6
Watagua County:					
Mine unknown	Clear water, wavy	6.0	12.3	15.4	10

TABLE 9.- Dielectric strength of domestic and foreign micas - Continued

DOMESTIC MUSCOVITES - Continued

Source	Classification	Average break-down voltage, kilovolts			Average deviation, percent
		1 mil	5 mils	9 mils	
North Carolina - Continued:					
Yancey County:					
Presley mine	Clear ruby, wavy	5.7	10.5	15.2	5
Barger mine	Clear water	7.0	9.4	11.5	6
Mine in Pisgah National Forest	Clear ruby, wavy	5.5	8.8	11.7	7
Gibbs mine	Clear water	5.4	9.4	10.4	5
Poll Hill mine	Light black-spotted	5.1	9.6	11.1	7
Balsam mine	Clear ruby	4.9	9.0	13.7	8
Fanny Gouge mine	Clear water	5.0	10.5	12.5	8
Do.	Black-stained	5.2	10.4	11.9	5
Cat Tail mine	Clear ruby, wavy	5.7	9.5	13.8	5
Westall mine	Clear light ruby	5.1	9.0	12.8	6
South Dakota:					
Custer County:					
John Wells mine, Sylvan Lake	Heavy-smoked ruby	3.7	10.8	17.9	5
Prospect 2 miles southeast of Custer	Stained ruby	5.0	8.3	10.9	5
Climax mine	Clear ruby	5.1	8.7	10.7	3

FOREIGN MUSCOVITES

Source	Classification	1 mil	5 mils	9 mils	Average deviation, percent
Argentina:					
Mine unknown	Black-stained	5.4	7.0	9.8	6
Do.	Light black-spotted	5.1	9.5	12.3	3
Brazil:					
Mine unknown	Clear and slightly stained.	6.0	8.7	11.4	3
Mine unknown	Clear and slightly stained.	6.0	8.7	11.4	3
Guatemala:					
Mine unknown	Clear dark green	5.0	12.8	16.3	10
India:					
Kodarma, Bihar (average of 7 samples)	Clear and slightly stained ruby.	6.2	8.6	10.9	4
Ganwan, Bihar (average of 6 samples)	do.	4.3	7.9	11.0	4
Mine unknown (average of 2 samples)	Clear ruby	4.4	8.9	12.1	5
Mine unknown	Fair-stained ruby	5.4	12.3	14.4	7
Do.	Stained ruby	5.3	11.4	15.8	6
Do.	Heavy-stained ruby	6.7	11.2	13.9	6
Do.	Black-spotted	5.3	8.6	13.1	7
Madras:					
Mine unknown	Red- and black-stained green.	3.9	8.9	9.5	8
Union of South Africa:					
Mine unknown	Clear water, first quality.	5.0	10.9	15.6	5

TABLE 9.- Dielectric strength of domestic and foreign micas - Continued

FOREIGN MUSCOVITES - Continued

Source	Classification	Average break-down voltage, kilovolts 1 mil	5 mils	9 mils	Average deviation, percent
Union of South Africa - Continued:					
Mine unknown	Red-stained	4.6	9.3	12.6	7

FOREIGN PHLOGOPITES

Source	Classification	1 mil	5 mils	9 mils	Average deviation, percent
Canada:					
Quebec:					
Lucky Reserve mine	Brown amber	4.5	10.2	12.1	6
Cantley, Cliff mine	do.	4.3	10.5	11.8	7
Madagascar:					
Mine unknown	Hard black amber	5.9	12.7	16.4	6
Do.	Medium soft amber	5.3	10.8	13.0	5

Table 10 collates the dielectric strengths listed in the preceding table according to the quality of the mica and the country of its origin. A study of this table discloses many surprising results. First, the average dielectric strength of 19 samples of clear domestic mica, all from different mines and from 5 States, is superior to the average shown by 15 samples of clear and slightly stained Indian mica. As this result is confirmed by the dielectric strengths of eight other samples of clear domestic mica, it is evident that the often quoted "superior dielectric strength of Indian mica" is not premised upon fact.

On the other hand, although the tests clearly demonstrate superiority in the dielectric strength of clear domestic mica as compared with that of clear and slightly stained Indian mica the author hesitates to draw a final conclusion because of the unavoidable scattering of results shown by the average deviations listed in table 9. Possibly, however, the seeming superiority in the dielectric strength of clear domestic mica may be due to its usual greater hardness or some other undetermined factor.

Comparison of the dielectric strengths of muscovite samples from Argentina, Brazil, Guatemala, and South Africa shows that in most tests these micas yielded excellent values and that they are probably as well suited for dielectric uses as domestic or Indian mica. The clear dark-green Guatemalan muscovite showed particularly high dielectric strengths at thicknesses of 5 and 9 mils, but the heavy red- and black-stained green Madras mica gave low results at all three thicknesses. The few samples of phlogopite tested showed average results, equal to those obtained with muscovite; the 2 samples of Madagascan muscovite exhibited excellent dielectric strengths, exceeding those of the 2 samples of Canadian amber mica at all thicknesses. The conclusion that Madagascan amber mica is superior to the Canadian as a dielectric is unjustified, however, because of the few samples tested.

The results obtained with stained mica indicate that, contrary to general belief, moderate staining with metallic oxides does not materially impair dielectric strength. Where staining, and in some instances even heavy staining, is accompanied by air bubbles the dielectric strength of the mica usually exceeds that of clear mica without air bubbles. For example, the 5 stained micas listed below, containing air bubbles in quantity, show dielectric strengths at all thicknesses superior to the average values of the 15 samples of clear and slightly stained Indian mica.

TABLE 10.- Dielectric strength of mica according to quality and country of origin

DOMESTIC MUSCOVITE

Classification	Number of samples	Average break-down voltage, kilovolts		
		1 mil	5 mils	9 mils
Clear ruby	19	5.6	10.0	13.2
Clear water	4	5.9	10.4	12.5
Clear pale green	1	5.8	9.4	12.9
Clear dark green	2	5.9	9.5	12.3
Clear honey	1	7.0	12.4	16.4
Stained ruby	2	5.8	8.6	12.1
Light black-spotted	2	5.4	10.0	13.5
Black-spotted	2	4.6	8.6	13.0
Black-stained	1	5.2	10.4	11.9
Light-smoked ruby	1	4.7	10.1	15.4
Heavy-smoked ruby	1	3.7	10.8	17.9

FOREIGN MUSCOVITE

India, clear and slightly stained	15	5.2	8.4	11.1
Brazil, clear and slightly stained	1	6.0	8.7	11.4
Guatemala, clear dark green	1	5.0	12.8	16.3
Union of South Africa, clear water	1	5.0	10.9	15.6
India, fair-stained ruby	1	5.4	12.3	14.4
India, stained ruby	1	5.3	11.4	15.8
Argentina, light black-spotted	1	5.1	9.5	12.3
Argentina, black-stained	1	5.4	7.0	9.8
Union of South Africa, red-stained	1	4.6	9.3	12.6
India, heavy-stained ruby	1	6.7	11.2	13.9
India, black-spotted	1	5.3	8.6	13.1
India (Madras), red- and black-stained green	1	3.9	8.9	9.5

FOREIGN PHLOGOPITE

Canada, brown amber	2	4.4	10.3	11.9
Madagascar, hard black amber	1	5.9	12.7	16.4
Madagascar, medium soft amber	1	5.3	10.8	13.0

Classification	1 mil	5 mils	9 mils
Domestic, light black-spotted	5.4	10.0	13.5
Domestic, black-stained	5.2	10.4	11.0
India, black-spotted	5.3	8.6	13.1
India, stained ruby	5.3	11.4	15.8
India, heavy-stained ruby	6.7	11.2	13.9

The results on some of the stained micas containing air bubbles were so surprising that they were checked and rechecked by further tests on additional specimens. Other micas were examined to determine if high dielectric strength, particularly at thicknesses of 5 and 9 mils, where the bubbles were not split out, coincided with the occurrence of numerous bubbles in the mica. Such a result was observed in a majority of the tests, and the highest dielectric strength (17.9 kv.) recorded in any of the tests at 9 mils was found in a "heavy-smoked ruby" mica from the Black Hills of South Dakota. Examination of this sample under a microscope revealed that the smoky effect was caused by clouds of innumerable minute bubbles.

This discovery of an apparent relation between high dielectric strength and the presence of air bubbles led to the classification of the specimens according to their air-bubble content. The curves shown in figure 9 were obtained by plotting the average dielectric strengths of four groups of muscovite specimens as classified by the Bureau of Standards.[17] Curves 1 and 2 represent the average values of 18 lots of domestic clear ruby mica and 9 lots of stained domestic ruby mica containing air bubbles. Curves 3 and 4 similarly represent average values of 3 lots of Indian clear ruby mica and 4 lots of Indian stained ruby mica containing air bubbles. In both sets of curves the dielectric strength of the mica containing stains and air bubbles is superior at all thicknesses to that of mica free from these imperfections.

It is believed that these surprising results are caused largely by the air bubbles and that staining alone will not produce them. This theory is borne out by the fact that specimens of stained mica apparently free from bubbles showed lower dielectric strengths than clear micas. Again, micas containing air bubbles but little or no staining showed unusually high dielectric strengths, for example, the ruby mica from South Dakota previously mentioned.

All of the above conclusions, however, are apparent rather than final, as the author realizes the danger of drawing general deductions from a small number of tests conducted under only one set of experimental conditions.

Special attention is called to the fact that the data in tables 9 and 10 are the results obtained with the particular method of test described. If the tests had been made with the 2-inch plate electrodes specified by the American Society for Testing Materials[18] for sheet insulating material the values would have been lower than those shown, as the plate electrodes find the weakest point in more than 3 square inches of mica as compared with a comparatively minute area tested by the spherical electrodes. Nevertheless, the relative values obtained with these two types of electrodes on fairly homogeneous material are in fair accord. For example, the following values of dielectric strength of a badly stained domestic ruby mica from the Fanny Gouge mine, Yancey County, N. C., and a clear Indian ruby mica were obtained in comparative tests with these different electrodes.

The results of the two methods of test on the badly stained domestic mica are plotted on curves 1 and 2, figure 8, which show but slight variations, although the vertical coordinates in the plot have been purposely doubled to emphasize any differences.

As the results obtained in these tests with different types of electrodes were so closeby parallel it was decided to run a series of tests on some of the same mica that had been previously tested with spherical electrodes to discover the influence of bubbles and staining on the dielectric strength as determined with 2-inch plate electrodes. Fourteen different muscovites, classified as clear, containing bubbles, and black or heavy-stained mica, were selected for these tests. The specimens were immersed in castor oil to prevent corona and flash-over and tested with a 60-cycle alternating voltage of virtually sine wave form. Table 12 records the results of the individual tests on each specimen of mica.

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[17] See footnote 15, p. 414.

[18] American Society for Testing Materials, Short-Time Dielectric Strength Test: Tentative Method D149-33T.

TABLE 11.- Dielectric strength of two micas as determined with spherical and with plate electrodes

BADLY STAINED DOMESTIC RUBY MICA

Thickness, mils	Dielectric strength, kilovolts per mil	
	Spherical 1-inch electrodes	A.S.T.M. 2-inch plate electrodes
1	4.35	2.75
2	2.65	1.90
3	1.95	1.52
4	1.58	1.34
5	1.39	1.19
6	1.25	1.10
7	1.15	1.03
8	1.10	1.00
9	1.08	.93
10	1.02	.90

CLEAR INDIAN RUBY MICA

Thickness, mils	Spherical 1-inch electrodes	A.S.T.M. 2-inch plate electrodes
4	2.00	1.42
5	1.72	1.26
6	1.55	1.10

TABLE 12.- Dielectric strength of various muscovites as determined with plate electrodes

Source	Classification	Thickness, mils	Break-down voltage, kilovolts
Strickland quarry, Connecticut	Clear ruby	2.2	5.60
		2.9	4.80
		5.0	7.10
Cleveland County, N.C.	do.	1.8	4.90
		5.1	6.50
		8.3	9.40
Hawk mine, Mitchell County, N.C.	do.	2.1	3.90
		3.9	6.20
		9.0	8.20
Gibbs mine, Yancey County, N.C.	do.	6.1	7.60
Malden mine, Georgia	do.	1.2	3.50
		1.8	5.10
		5.2	7.40
		7.0	8.70
		8.8	9.20

TABLE 12.- Dielectric strength of various muscovites as determined with plate electrodes - Continued

Source	Classification	Thickness, mils	Break-down voltage, kilovolts
Hibbs quarry, Oxford, Maine	Clear ruby	1.3	3.50
		3.1	5.10
		6.0	7.10
		10.0	8.60
		10.5	9.50
Strickland quarry, Connecticut	Clear, honey color, containing many bubbles.	1.1	3.07
		2.5	4.55
		6.4	7.24
		11.9	9.25
		11.9	10.40
India	Ruby, heavily stained and containing many air bubbles.	1.1	3.07
		2.2	4.60
		3.1	5.07
		5.5	6.80
		6.6	7.62
		8.2	7.85
		9.4	8.18
John Wells mine, South Dakota	Ruby, containing clouds of minute bubbles.	2.2	4.16
		3.1	4.71
		3.8	5.32
		4.6	5.92
		8.3	8.31
Africa	Red-stained	1.7	4.00
		2.2	3.04
		5.9	8.02
		7.2	8.96
		7.2	7.85
		7.8	8.64
Do.	Black-stained	2.0	3.48
		4.7	5.10
		6.6	7.19
		6.6	7.10
Argentine	do.	.9	2.93
		2.7	4.93
		4.7	6.36
		4.7	6.02
		10.0	8.78
Do.	do.	.7	2.11
		1.6	3.34
		3.8	5.04
		5.2	5.86
		5.7	6.03
		10.0	8.79
India	do.	1.4	2.96
		1.8	3.78
		4.6	6.24
		5.1	6.08
		8.9	8.48

The results obtained on the six clear micas were plotted as break-down voltages in kilovolts against thickness in mils, and a smooth curve was drawn through the resulting points. The results obtained on the 3 micas containing bubbles and on the 5 micas with black or heavy staining were similarly plotted. From the smooth curves representing the 3 different groups of mica break-down voltages were read at exactly 1, 3, 5, 7, and 9 mils. These values, together with the dielectric strength in kilovolts per mil, are recorded in table 13.

TABLE 13.- Dielectric strength of various classifications of muscovite as determined with plate electrodes

CLEAR MICA (6 specimens, 20 tests)

	Thickness, mils				
	1	3	5	7	9
Break-down voltage, kilovolts	3.25	5.35	6.80	7.95	8.94
Dielectric strength, kilovolts per mil	3.25	1.78	1.36	1.14	.99

MICA CONTAINING BUBBLES (3 specimens, 17 tests)

Break-down voltage, kilovolts	3.00	4.82	6.35	7.58	8.61
Dielectric strength, kilovolts per mil	3.00	1.61	1.27	1.08	.96

BLACK AND HEAVY-STAINED MICA (5 specimens, 26 tests)

Break-down voltage, kilovolts	2.62	4.44	6.10	7.55	8.90
Dielectric strength, kilovolts per mil	2.62	1.48	1.22	1.08	.99

Inspection of table 13 shows that the clear micas have a slightly greater average dielectric strength than those containing bubbles and that these last in turn show a higher average dielectric strength than the group of black and heavy-stained micas. The differences however, are slight, particularly at thicknesses of 5 mils and over, and at 9 mils they virtually disappear.

The results with the 2-inch plate electrodes unquestionably represent the voltage a mica would withstand in most instances of actual use much more exactly than those obtained with spherical electrodes; the writer therefore urges the general adoption of the 2-inch plate electrodes, used in accordance with the method recommended by the American Society for Testing Materials, as standard for determining the dielectric strength of micas.

Power Factors of Micas[19]

The power factor of mica is the ratio (usually expressed as percent) of the total power loss in a condenser in which it is the dielectric to the total volt-amperes supplied the condenser. The extent to which mica will heat and its power loss under an electric load are of great importance if the mica is to be used in condensers. Direct measurement of the heat generated when a mica is electrically charged is impracticable, but the power factor furnishes a reliable guide as to the amount of this heat. A mica with a high power factor will generate much heat and one with a low power factor, little heat. The power factor of a mica therefore determines its suitability for use in condensers.

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[19] The tests described were planned by and conducted under the supervision of E. L. Hall, National Bureau of Standards.

In view of the lack of trustworthy data from which a comparison of the power factors of domestic and foreign mica might be made, the National Bureau of Standards agreed to make the required tests and spent a considerable sum in building an electrically shielded room in which to conduct them and in assembling special apparatus. The data submitted are the results of measurements upon both domestic and foreign micas to determine their relative suitability for use in electrical condensers for radio frequencies.

The power loss was measured by determining the resistance of a circuit containing a condenser prepared from an individual sheet of mica and again measured after the sample condenser was replaced by a standard condenser whose losses were either negligible or known. The difference between the two measurements gives the resistance of the sample condenser. The power factor in percent is then calculated from the equation:

$$\text{Power factor (percent)} = 6.283 \times RCf \times 10^{-7},$$

where

R = resistance of the sample in ohms,
C = capacitance of the sample in micromicrofarads,
f = frequency in kilocycles per second at which the measurement was made.

The dielectric constant was also calculated from the observed data by the following equation:

$$K = 11.3\ Ct/S,$$

where

K = the dielectric constant,
C = capacitance of the sample in micromicrofarads,
t = thickness of the sample in centimeters,
S = area of sample in square centimeters.

The dielectric constant of mica is the ratio of the capacitance of a condenser in which it is the dielectric to the capacitance of a similar condenser in which the dielectric is a vacuum.

Further details of the method of measurement may be found in Bureau of Standards Scientific Paper 471, Methods of Measurement of Properties of Electrical Insulating Materials, and in the American Society for Testing Materials specifications, Tentative Methods of Testing Electrical Insulating Materials for Power Factor and Dielectric Constant at frequencies of 100 to 1,500 kilocycles, A.S.T.M. Designation D150-27T.

Test condensers were made by applying linseed oil to both sides of a mica sheet and then wiping the surfaces lightly with a clean, dry cloth. One side of the mica was coated with tinfoil, the thin film of linseed oil causing the foil to adhere tightly. One or two pieces of tinfoil 3 by 4 cm were then attached to the opposite side of the mica in the same manner. Care was taken to apply these small tinfoil plates to sections free from air pockets and of apparent uniformity. Two pieces of tinfoil on one side gave two test condensers for a given mica sample, although measurements were not made on all the condensers thus prepared. The capacity of the condenser was first measured on a direct-reading microfarad meter at 500 cycles per second. This measurement was of value in starting the measurements at radio frequencies. Readings of the relative humidity and the temperature of the room were also taken at the time of the measurements at radio frequencies.

Power-factor measurements were made on most samples at four frequencies between 100 and 1,000 kc. A few tests on some of the heavy-stained micas immediately indicated their unsuitability for use in condensers for radio purposes, so only a few of the heavy-stained samples were tested. No attempt was made to study the effect on the power factor caused by changes in temperature or humidity, which are known to alter its value. Tables 14 and 15 list the results of the tests.

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas

MUSCOVITES

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm²	Frequency, kc	Dielectric constant, k	Power factor, percent
Big Ridge mine, Haywood County, N.C.	Clear........	24.5	37.2	0.106	12.06	108.2	6.58	0.01
		25.0	37.2			242.8	6.58	.01
		25.1	37.2			544.0	6.57	.02
		25.2	37.2			778.0	6.57	.02
		25.2	37.2			1,010.0	6.57	.03
Do.	do.	22.8	23.5	.175	12.09	134.5	6.99	.01
		23.0	23.5			300.0	6.99	.01
		23.3	23.5			675.0	6.99	.01
		23.5	23.5			962.0	6.99	.02
Hibbs quarry, Oxford County, Me.	do.	25.9	16.0	.340	12.09	178.0	7.37	.01
		26.0	16.0			401.0	7.37	.01
		....	32.0			401.0	7.37	.01
		23.5	27.5			608.1	7.34	.01
		25.9	16.0			900.0	7.34	.01
Johnson mine, Avery County, N.C.	do.	24.4	31.0	.358	12.09	185.6	7.09	.01
		24.4	31.0			419.5	7.09	.01
		24.4	31.0			620.0	7.09	.02
		25.0	30.0			940.0	7.11	.01
Do.	do.	24.9	30.0	.358	12.09	185.6	7.11	.02
		24.6	30.0			419.0	7.11	.02
		24.3	30.0			619.0	7.11	.02
		24.0	30.0			942.0	7.11	.02
Malden mine, Upson County, Ga.	do.	27.2	47.0	.198	12.11	141.0	7.00	.01
		27.1	47.0			315.0	7.00	.01
		27.6	47.0			482.0	7.00	.01
		27.4	47.0			710.0	7.00	.01
Westhall mine, Yancey County, N.C.	do.	23.8	30.1	.246	12.20	155.0	7.15	.01
		24.1	30.0			262.5	7.16	.01
		24.3	30.1			529.0	7.15	.01
		24.6	30.1			782.0	7.16	.01
Do.	do.	23.8	30.1	.246	12.20	154.8	7.16	.01
		24.0	30.1			262.1	7.16	.01
		24.3	30.1			528.0	7.16	.01
		24.5	30.1			781.0	7.16	.02

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas - Continued

MUSCOVITES - Continued

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
Alexandria, N.H.	Clear	25.7	66.5	0.195	12.04	140.2	7.10	0.02
		25.7	66.5			314.0	7.10	.02
		25.8	66.5			704.0	7.11	.03
		25.9	66.5			1,006.0	7.11	.03
India	do.	25.8	47.0	.183	12.14	135.0	7.16	.01
		26.1	47.0			302.0	7.16	.01
		26.1	47.0			677.0	7.16	.01
		26.3	47.0			966.0	7.16	.01
Do.	do.	26.2	25.0	.091	12.01	120.0	7.91	.01
		26.2	25.0			305.0	7.90	.01
		26.2	25.0			658.0	7.90	.03
		26.2	25.0			861.0	7.90	.01
Do.	do.	25.0	30.3	.270	12.28	160.3	7.16	.01
		25.0	30.3			278.0	7.16	.01
		25.0	30.3			548.0	7.16	.01
		25.0	30.3			812.0	7.16	.01
Do.	do.	25.5	59.5	.190	11.96	139.0	7.06	.02
		25.3	59.5			311.0	7.06	.02
		25.4	59.5			700.0	7.06	.02
		25.5	59.5			1,000.0	7.08	.03
Guatemala	Clear green.	26.3	...	.280	12.09	165.0	7.17	.07
		26.4	...			556.0	7.17	.04
		26.4	55.0			826.0	7.19	.03
		26.4	55.0			1,550.0	7.17	.03
Ruggles mine, N.H.	Clear with a few air bubbles.	24.8	57.0	.351	12.10	181.0	7.32	.11
		25.0	57.0			307.0	7.33	.09
		25.2	57.0			608.0	7.33	.07
		25.4	57.0			914.0	7.32	.06
Fanny Gouge mine, Mitchell County, N.C.	Slightly stained.	23.0	31.0	.160	12.33	138.0	5.84	.21
		23.2	31.0			309.0	5.84	.16
		24.2	31.0			694.0	7.07	.12
		24.2	31.0			995.0	5.86	.11
		24.2	31.0			2,000.0	5.83	.08
Do.	do.	23.6	44.0	.175	12.33	126.5	7.69	.01
		23.6	44.0			283.0	7.69	.02
		23.6	44.0			634.0	7.69	.02
		23.6	44.0			911.0	7.69	.03
		23.6	44.0			911.0	7.69	.03
Hibbs quarry, Oxford County, Me.	do.	25.5	37.2	.216	12.06	147.5	6.98	.02
		25.3	37.2			330.0	6.98	.02
		25.5	37.2			503.0	6.98	.02
		25.5	37.2			742.0	6.98	.02
		25.6	37.2			1,067.0	6.98	.03

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas - Continued

MUSCOVITES - Continued

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
G. E. Co., Alexandria, N.H.	Slightly stained.	25.3	60.5	0.140	12.12	121.0	6.87	0.03
		25.5	60.5			281.0	6.87	.03
		25.5	60.5			614.0	6.87	.04
		25.5	60.5			870.0	6.87	.04
Do.	do.	23.8	27.5	.208	12.31	143.8	7.04	.02
		23.0	27.5			321.0	7.04	.03
		23.4	27.5			488.5	7.04	.03
		23.4	29.0			723.0	7.04	.03
Fanny Gouge, Mitchell County, N.C.	Heavily stained.	23.2	....	.210	11.63	227.0	8.64	(1)
		23.2	....			304.0	8.64	(1)
Do.	Heavily stained.	23.0	43.0	.210	11.99	180.5	7.18	1.39
		26.0	43.0			181.0	7.16	1.40
		26.0	43.0			325.0	7.12	1.20
		23.0	43.0			325.0	7.16	1.18
		23.0	43.0			732.0	7.11	.94
		26.0	43.0			733.0	7.21	1.10
		23.2	43.0			1,047.0	7.10	.81
		26.0	43.0			1,050.0	7.09	1.10
		24.4	43.0			1,050.0	7.09	.82
Do.	do.	....	....	.210	12.03	310.0	7.94	5.4
Do.	do.	24.8	....	.190	12.09	119.5	9.64	(1)
Argentine	do.	24.8	49.0	.098	12.11	464.0	8.83	8.36
India	do.	24.5	34.0	.396	12.26	117.5	8.48	(1)
		24.5	34.0			302.0	8.39	(1)
		24.5	34.0			924.0	8.00	(1)

PHLOGOPITES (AMBER MICAS)

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
Madagascar	Hard, clear, pale green.	28.2	62.5	0.142	12.12	129.4	7.07	1.12
		28.8	62.5			290.0	6.04	.75
		28.7	62.5			661.0	5.77	.47
		38.5	62.5			928.0	5.77	.38
Do.	Soft, opaque.	26.5	....	.292	12.12	190.0	5.41	7.12

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[1] Losses were too large to measure conveniently.

TABLE 15.- Summary of power factors and dielectric constants of micas tested

Number of samples	Origin	Kind	Dielectric constant		Power factor	
			Average	Spread	Average	Spread
9	United States	Clear muscovite	7.06	6.57-7.37	0.014	0.01-0.03
4	India	do.	7.32	7.06-7.91	.014	.01- .03
1	Guatemala	Clear green muscovite	7.18	7.17-7.19	.04	.03- .07
1	New Hampshire	Unstained muscovite with air bubbles.	7.33	7.32-7.33	.08	.06- .11
5	United States	Slightly stained muscovite	6.93	5.83-7.69	.04	.01- .21
2	do.	Heavy-stained muscovite	7.22	7.09-7.94	1.53	.82-5.4
1	Argentina	do.	8.83	....	8.36	....
1	India	do.	8.29	8.00-8.48	(1)	(1)
2	Madagascar	Phlogopite	....	5.41-7.07	....	.38-7.12

[1] Losses were too large to measure conveniently.

The tests show that the power factor of clear domestic mica compares favorably with that of the best Indian product; in fact both the average power factor and the spread of power-factor values obtained from 9 samples of clear domestic mica are identical with those of the 4 lots of clear Indian mica tested. The measurements on 5 lots of slightly stained muscovites and 1 sample containing a few air bubbles show that these grades of mica are unsuited for condensers at radio frequencies. Heavy-stained muscovite and phlogopite yielded such high power factors as to preclude their use for condensers.

With the heavy-stained muscovites, the phlogopites, the clear domestic muscovite containing air bubbles, and the clear Guatemalan mica, the power factor is a function of the frequency, decreasing as the frequency increases. There is no evidence, however, that the dielectric constant is a function of frequency or that there is any close relation between the amount of staining and the dielectric constant.

The tests entirely disprove the frequent assertion that domestic mica is inferior to Indian for use in radio condensers. Only the best grades of the Indian product are used for condenser films and, of course, the best domestic micas must be selected to compare with them.

Physical Changes in Micas When Heated to Elevated Temperatures[20]

Heating tests were conducted by the Bureau of Standards on 19 lots of foreign and domestic micas furnished by the writer to determine how they would withstand elevated temperatures. Of these micas 6 were domestic muscovites, 1 domestic biotite, 3 Indian micas, 1 Guatemalan muscovite, 1 Brazilian muscovite, 3 Canadian phlogopites, and 4 Madagascan phlogopites.

The mica was cut into rectangles, 1 by 2.5 cm, and split to thicknesses of 2 to 4 mils, all samples of each lot being of the same thickness. Eight samples were selected to represent each lot. One of these was not treated. The rest were sorted into 7 groups with similar specimens from the other 18 lots of mica, making 7 groups of 19 samples each. The various groups were heated on an alumina plate in a furnace of sensibly uniform temperature to 600°, 700°, 800°, 900°, 1,000°, 1,100°, and 1,200° C., respectively, and held at these temperatures for one half hour. The temperatures were measured with a pyrometer and are accurate to within - 10° C.

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[20] The tests described were planned by and conducted under the supervision of Frank R. Caldwell, National Bureau of of Standards.

The rate of heating was rapid, the time required to reach the test temperatures ranging from about 35 minutes in the test at 600° C. to about 1 1/2 hours in the one at 1,200° C. No external force was applied to the samples during the tests. Thus the deformations and changes in other properties observed are due only to exposure to the various temperatures to which the specimens were subjected. Changes in the properties of the mica caused by the heating are shown in table 16. The properties listed are:

1. Color graded from 1 (very light) to 7 (very dark).
2. Condition of surface graded from 1 (glassy) to 7 (very rough), A (slightly wrinkled), B (badly wrinkled), C (slightly checked), and D (badly checked).
3. Opacity graded from 1 (clear) to 7 (opaque).
4. Separation of laminae graded from 1 (no separation) to 5 (extreme separation) and in some cases A (slightly sintered).
5. Structure graded from 1 (withstands bending) to 4 (does not withstand bending), A (hard) and B (soft).
6. Size before and after heating.

TABLE 16.- Results of heating micas to elevated temperatures

CLEAR MUSCOVITE, ALEXANDRIA MINE, N.H.

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	1 yellow	1	2	1	1A	25 by 10 by 0.2
600	1 yellow, brown stains.	1	2	1	1A	25 by 10 by 0.2
700	3 gray, brown stains.	2	3	1	1A	25 by 10 by 0.2
800	5 gray	2	7	2	3C	25 by 10 by 0.7
900	5 brownish gray	2	7	2	3C	25 by 10 by 0.7
1,000	2 brown, dark stains.	3	7	3	4B	25 by 10 by 1
1,100	2 gray, brown stains.	3	6	2	4A	25 by 10 by 0.5
1,200	2 gray	5	6	B	4A	25 by 10 by 0.5

CLEAR MUSCOVITE, ABERNATHY MINE, N.C.

Normal	2 gray	1	4	1	1A	25 by 10 by 0.3
600	3 gray	1	4	1	1A	25 by 10 by 0.3
700	5 gray	1	5	1	1A	25 by 10 by 0.3
800	4 gray	2	7	3	3B	25 by 10 by 1.5
900	do.	2	7	4	3C	25 by 10 by 2.5
1,000	do.	2	7	3	3C	25 by 10 by 2
1,100	do.	5	7	2A	4A	25 by 10 by 1
1,200	2 brown	6B	7	B	4A	24 by 8 by 1.5 (warped)

TABLE 16.- Results of heating micas to elevated temperatures - Continued

CLEAR MUSCOVITE, HIBBS QUARRY, ME.

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	2 pinkish gray	1	3	1	1A	25 by 10 by 0.3
600	2 gray	1	3	1	1A	25 by 10 by 0.3
700	3 gray, brown stain.	1	3	1	1A	25 by 10 by 0.3
800	5 gray	2	7	4	3B	25 by 10 by 1.5
900	do.	2	7	4	3B	25 by 10 by 1.5
1,000	1 gray	2	6	3	3A	25 by 10 by 1.5
1,100	do.	3	6	2A	4A	25 by 10 by 1
1,200	White	6B	7	B	4A	22 by 9 by 1.5 (warped)

CLEAR MUSCOVITE, SYLVAN LAKE, S.DAK.

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	2 pink	1	4	1	1A	25 by 10 by 0.3
600	2 gray	1	3	1	1A	25 by 10 by 0.3
700	3 gray	1	5	1	1A	25 by 10 by 0.3
800	5 gray	3	7	4	2B	25 by 10 by 3
900	4 gray	2	7	4	3B	25 by 10 by 2
1,000	1 gray	2	6	4	3C	25 by 10 by 2
1,100	do.	3	6	3	4A	25 by 10 by 1.5
1,200	White	6B	7	B	4A	23 by 8 by 0.5 to 3 (warped).

CLEAR GREEN MUSCOVITE, GUATEMALA

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	5 green	1	4	1	1A	25by 10 by 0.3
600	6 green	1	5	1	1A	25 by 10 by 0.3
700	2 green	1	6	2	1A	25 by 10 by 0.3
800	6 greenish brown	3	7	4	3C	25 by 10 by 3
900	6 brown	2	7	4	3C	25 by 10 by 2.5
1,000	do.	2	7	4	3C	25 by 10 by 3.5
1,100	3 brown	5Bd	7	4	4C	25 by 10 by 3
1,200	do.	7	7	B	B	14 by 4 by 5

CLEAR MUSCOVITE, INDIA

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	3 pinkish gray	1	4	1	1A	25 by 10 by 0.4
600	2 gray	1	2	1	1A	25 by 10 by 0.4
700	do.	2	5	1	2B	25 by 10 by 0.4
800	5 gray	3	7	4	3C	25 by 10 by 3.5
900	4 gray	2	7	4	3C	25 by 10 by 3
1.000	1 gray	2	6	4	3C	25 by 10 by 3
1,100	do.	2	7	3	4C	25 by 10 by 2
1,200	do.	2	7	3	4A	25 by 10 by 2

TABLE 16.- Results of heating micas to elevated temperatures - Continued

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
CLEAR MUSCOVITE, CLIMAX MINE, S.D.						
Normal	3 pinkish gray	1	3	1	1A	25 by 10 by 0.3
600	3 gray	1	3	1	1A	25 by 10 by 0.3
700	do.	1	4	1	1A	25 by 10 by 0.3
800	5 gray	2	7	4	2B	25 by 10 by 2
900	4 gray	2	7	4	3B	25 by 10 by 2
1,000	1 gray	2	6	4	3B	25 by 10 by 2
1,100	do.	2	6	3	4B	25 by 10 by 1.5
1,200	do.	3	6	2	4A	25 by 10 by 1
CLEAR MUSCOVITE, AVON, IDAHO						
Normal	2 gray	1	3	1	1A	25 by 10 by 0.4
600	4 gray	1	4	1	1A	25 by 10 by 0.4
700	5 gray, brown stains.	2	7	3	2A	25 by 10 by 1
800	do.	2	7	3	3B	25 by 10 by 1.5
900	do.	2	7	3	3C	25 by 10 by 1.5
1,000	3 gray, dark-brown stains.	2	7	3	4B	25 by 10 by 2
1,100	2 gray, brown stains.	3	7	2A	4A	25 by 10 by 1
1,200	1 brown	5A	7	B	4A	25 by 9.5 by 2 (warped)
SLIGHTLY STAINED MUSCOVITE, MADRAS, INDIA						
Normal	3 greenish gray	1	3	1	1A	25 by 10 by 0.4
600	4 greenish gray	1	3	1	1A	25 by 10 by 0.4
700	5 gray	2	6	3	2A	25 by 10 by 2
800	5 brownish gray	3	7	3	3B	25 by 10 by 1
900	4 grayish brown	3	7	4	3C	25 by 10 by 2
1,000	3 brown	3	7	3	3C	25 by 10 by 1.8
1,100	4 gray	3	7	2	4A	25 by 10 by 0.7
1,200	do.	6B	7	B	4A	22 by 9 by 1 (warped)
SLIGHTLY STAINED MUSCOVITE, BRAZIL						
Normal	2 gray	1	3	1	1A	25 by 10 by 0.2
600	1 gray	1	2	1	1A	25 by 10 by 0.2
700	4 gray	1	5	1	1A	25 by 10 by 0.2
800	6 gray	2	6	2	2C	25 by 10 by 1
900	6 brownish gray	2	7	3	3C	25 by 10 by 1
1,000	3 brown	3	6	3	3C	25 by 10 by 1
1,100	2 gray	5	6	2A	4A	25 by 10 by 0.7
1,200	1 gray	6B	7	B	4A	20 by 10 by 1.5 (warped)

TABLE 16.- Results of heating micas to elevated temperatures - Continued

GOOD STAINED MUSCOVITE, INDIA

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal....	3 pinkish gray........	1	3	1	1A	25 by 10 by 0.2
600..........	1 gray........................	1	2	1	1A	25 by 10 by 0.2
700..........	2 gray, brown stains.	2	5	1	1A	25 by 10 by 0.2
800..........	5 gray........................	3	7	3	3C	25 by 10 by 2
900..........	4 gray........................	2	7	3	3C	25 by 10 by 1.5
1,000......	1 gray, brown stains.	2	6	3	3B	25 by 10 by 1
1,100......	1 gray, brown stains.	3	7	3	4B	25 by 10 by 0.6
1,200......	1 gray, brown stains.	5	7	B	4A	25 by 10 by 0.3

LIGHT-GRAY PHLOGOPITE, CANADA

Normal....	4 gray.......................	2	5	1	1A	25 by 10 by 0.2
600..........	do.	2	5	1	1A	25 by 10 by 0.2
700..........	do.	2	5	1	1A	25 by 10 by 0.2
800..........	do.	2	5	1	1A	25 by 10 by 0.2
900..........	do.	2	5	1	2A	25 by 10 by 0.2
1,000......	do.	2	6	2	2A	25 by 10 by 0.2
1,100......	3 gray.......................	3	7	2	3B	25 by 10 by 0.2
1,200......	1 brown.....................	6D	7	2	4A	25 by 10 by 0.5

DARK-GRAY PHLOGOPITE, LUCKY RESERVE MINE, QUEBEC, CANADA

Not heated.	5 gray.......................	2	6	1	2B	25 by 10 by 0.2
600..........	do.	2	6	1	2B	25 by 10 by 0.2
700..........	do.	2	6	1	2B	25 by 10 by 0.2
800..........	do.	2	6	1	2B	25 by 10 by 0.2
900..........	do.	2	6	2	2A	25 by 10 by 0.3
1,000......	5 brownish gray......	2	6	2	2A	25 by 10 by 0.7
1,100......	3 brownish gray......	3	7	2	3B	25 by 10 by 0.7
1,200......	3 brown.....................	5D	7	2	4C	25 by 10 by 0.8

DARK-GRAY PHLOGOPITE, CLIFF MINE, QUEBEC, CANADA

Normal....	6 gray.......................	2	6	1	1A	25 by 10 by 0.3
600..........	5 gray.......................	2	7	4	2C	25 by 10 by 2.5
700..........	do.	2	7	4	2B	25 by 10 by 1.5
800..........	5 brownish gray...	2	7	4	3C	25 by 10 by 1.5
900..........	3 brown.....................	2	7	4	3C	25 by 10 by 2
1,000......	do.	2A	7	4	3D	25 by 10 by 3
1,100......	2 brown.....................	3C	7	4	3D	25 by 10 by 3
1,200......	1 brown......	5D	7	4A	4D	25 by 10 by 2.5

TABLE 16.- Results of heating micas to elevated temperatures - Continued

SOFT PHLOGOPITE, MADAGASCAR

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeter
Normal	5 gray	3	4	1	3B	25 by 10 by 0.2
600	do.	3	4	1	3B	25 by 10 by 0.2
700	do.	3	4	1	3B	25 by 10 by 0.2
800	do.	3	4	1	3B	25 by 10 by 0.2
900	5 brownish gray	3	5	1	3B	25 by 10 by 0.2
1,000	5 brown	3	5	2	3B	25 by 10 by 0.5
1,100	5 brownish gray	3	6	2	3B	25 by 10 by 0.5
1,200	1 brown	6D	7	2	4C	25 by 10 by 0.5

MEDIM SOFT PHLOGOPITE, MADAGASCAR

Normal	5 gray	3	6	1	3A	25 by 10 by 0.4
600	do.	3	6	2	3B	25 by 10 by 0.6
700	do.	3	6	2	3C	25 by 10 by 0.6
800	do.	3	7	3	3C	25 by 10 by 1
900	do.	3	7	3	3C	25 by 10 by 1
1,000	do.	3	7	4	3C	25 by 10 by 2
1,100	3 brownish gray	3C	7	4	3D	25 by 10 by 2.5
1,200	3 brown	5D	7	4	4C	25 by 10 by 1.5

MEDIUM HARD PHLOGOPITE, MADAGASCAR

Normal	7 gray	2	6	1	3A	25 by 10 by 0.4
600	5 gray	2	6	1	3A	25 by 10 by 0.4
700	do.	2	6	1	3A	25 by 10 by 0.4
800	do.	2	6	2	3A	25 by 10 by 0.7
900	do.	2	7	3	3C	25 by 10 by 2
1,000	5 brownish gray	3	7	4	3C	25 by 10 by 2
1,100	3 brownish gray	3	7	4	4B	25 by 10 by 1.5
1,200	3 brown	5D	7	4	4C	25 by 10 by 2

HARD PHLOGOPITE, MADAGASCAR

Normal	Black	1	6	1	2A	25 by 10 by 0.3
600	do.	1	6	1	2A	25 by 10 by 0.3
700	do.	1	6	1	2A	25 by 10 by 0.3
800	do.	1	6	2	2A	25 by 10 by 0.8
900	6 brown	2	7	3	3B	25 by 10 by 1
1,000	do.	2	7	3	3C	25 by 10 by 1
1,100	4 brown	2	7	3	3D	25 by 10 by 1
1,200	3 brown	4D	7	2	4D	25 by 10 by 0.4

TABLE 16.- Results of heating micas to elevated temperatures - Continued

BIOTITE, SOUTH DAKOTA

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal....	7 brown....................	1	6	1	1A	25 by 10 by 0.4
600..........	do.	2BD	7	5	3C	25 by 10 by 4
700..........	6 brown....................	3	7	3	3B	25 by 10 by 2
800..........	do.	2B	7	3	3C	25 by 10 by 2
900..........	do.	3	7	3	3C	25 by 10 by 2
1,000......	5 brown....................	3	7	3	3B	25 by 10 by 1.5
1,100......	do.	5	7	B	4B	25 by 10 by 2
1,200......	6 brown....................	6	7	B	4A	21 by 8.5 by 1.5 (warped)

There was no perceptible change in the micas after heating at 600° C. except that the biotite swelled to 10 times its original thickness and the phlogopite from the Cliff Mine, Quebec, Canada, swelled to about 8 times its original thickness. At 700° C. the three samples of Indian mica became opaque, and the Madras mica swelled notably. At this temperature 2 of the domestic muscovites, 1 from the Hibbs quarry in Maine and 1 from the Climax mine in South Dakota, remained transparent and were apparently unaffected. Four of the domestic muscovites lost their transparency at 700° C.; with the exception of the mica from Avon, Idaho, none changed as much as the Indian samples. At 700° C. both the muscovites from Guatemala and Brazil became opaque but did not swell. The Canadian phlogopite, affected at 600° C., showed further physical changes at 700° C. At 800° C. all muscovite samples showed radical changes, most of them swelling considerably. Two of the Canadian and all of the Madagascan phlogopites were not notably affected at this temperature. The best Canadian phlogopites and the soft Madagascan phlogopite withstood 1,100° C. without much apparent change except a lightening in color, but at 1,200° C. all the micas blistered and were so changed as to be unsuitable for use. It is interesting to note that the Guatemala muscovite, which is commonly thought to be unfit for heating elements, stood 600° C. without any apparent change and at 700° C. was no more affected than the best grades of Indian muscovite. At 1,200° C., however, it fused and contracted to one quarter of its original size.

Table 17 lists the micas in the order of their ability to withstand temperatures of 700°, 900°, and 1,100° C., respectively, according to the average grading of four independent observers who utilized a point system. A low score indicates excellent resistance and a high score, great physical changes; the best micas therefore are listed at the top of the columns. In grading the micas at a given temperature no attention was paid to the stages through which they had previously passed; that is, if a sample showed undesirable characteristics at 700°C. and seemed to have lost them at 900° C. it was graded at 900° C. solely on its characteristics after being subjected to this temperature.

It should be remembered that the order of arrangement in this table was determined by tests in which the specimens were under no external stresses; should conditions be altered in this respect the position of the micas in the tables might be changed considerably. For example, if one of the micas whose laminae separated considerably but whose other qualities remained desirable were placed under pressure it is possible that the mica would change places with one whose other properties were not as desirable.

TABLE 17.- Apparent order in which various micas are able to withstand elevated temperatures

Temperature, 700° C.

	Kind of mica	Points
1.	Phlogopite, light, Canada	16
2.	Muscovite, Abernathy mine, N.C.	17
3.	Phlogopite, hard, Madagascar	19
4.	Phlogopite, soft, Madagascar	20
5.	Phlogopite, medium hard, Madagascar	22
6.	Muscovite, Climax mine, S.Dak.	24
7.	Phlogopite, dark, Lucky Reserve mine, Canada	25
8.	Muscovite, Alexandria mine, N.H.	27
9.	Muscovite, good-stained, Indian	24
10.	Muscovite, Hibbs quarry, Maine	37
11.	Phlogopite, medium soft, Madagascar	40
12.	Muscovite, clear, Indian	43
13.	Muscovite, slightly stained, Brazil	44
14.	Muscovite, Sylvan Lake, S.Dak.	47
15.	Muscovite, Quatemala	61
16.	Muscovite, Avon, Idaho	62
17.	Phlogopite, Cliff mine, Canada	69
18.	Muscovite, Madras, India	72
19.	Biotite, South Dakota	74

Temperature, 900° C.

	Kind of mica	Points
1.	Phlogopite, light, Canada	6
2.	Phlogopite, soft, Madagascar	7
3.	Phlogopite, dark, Lucky Reserve mine, Canada	13
4.	Muscovite, Alexandria mine, N.H.	20
5.	Phlogopite, hard, Madagascar	21
6.	Phlogopite, medium soft, Madagascar	22
7.	Muscovite, good-stained, Indian	27
8.	Phlogopite, medium hard, Madagascar	32
9.	Muscovite, slightly stained, Brazil	33
10.	Muscovite, Avon, Idaho	38
11.	Muscovite, Hibbs quarry, Maine	47
12.	Muscovite, Climax mine, S.Dak.	55
13.	Muscovite, clear, Indian	56
14.	Muscovite, Sylvan Lake, S.Dak.	57
15.	Muscovite, Madras, India	58
16.	Biotite, South Dakota	60
17.	Muscovite, Guatemala	65
18.	Muscovite, Abernathy mine, N.C.	66
19.	Phlogopite, Cliff mine, Canada	75

TABLE 17.- Apparent order in which various micas are able to withstand elevated temperatures - Continued

Temperature, 1,100° C.

Kind of mica	Points
1. Phlogopite, soft, Madagascar	6
2. Phlogopite, light, Canada	15
3. Phlogopite, hard, Madagascar	16
4. Muscovite, Madras, India	24
5. Muscovite, Alexandria mine, N.H.	25
6. Muscovite, Hibbs quarry, Me.	25
7. Phlogopite, dark, Lucky Reserve mine, Canada	28
8. Muscovite, good-stained, Indian	31
9. Muscovite, Sylvan Lake, S.Dak.	32
10. Phlogopite, medium hard, Madagascar	40
11. Muscovite, Avon, Idaho	41
12. Muscovite, Climax mine, S.Dak.	42
13. Muscovite, Abernathy mine, N.C.	51
14. Muscovite, clear, Indian	54
15. Muscovite, slightly stained, Brazil	54
16. Phlogopite, medium soft, Madagascar	57
17. Phlogopite, Cliff mine, Canada	67
18. Biotite, South Dakota	73
19. Muscovite, Guatemala	74

The results of these heating tests distinctly favor domestic muscovites compared with the Indian muscovites and conclusively disprove statements to the effect that the Indian product has a higher resistance to heat. They also show the marked superiority of the soft, light-colored phlogopites over muscovites in heat resistance and suggest the use of these phlogopites where temperatures exceed 600° C.

GENERAL CONCLUSIONS

In conclusion, the tests made by the National Bureau of Standards show no notable differences in any of the more important physical properties of domestic and foreign micas. Their dielectric strength, change on heating, and power factors are virtually identical; other properties, such as flexibility and hardness, may be duplicated in comparable grades. To what, then, must the preference for Indian mica by many consumers be attributed? The answer is: To the more careful preparation and better grading of the Indian product. This is its only legitimate claim to superiority, but commercially it is the key to its dominance of the world market. Although some consumers think that Indian mica is inherently superior to all other micas, the Indian producers are under no such misapprehension. G. V. Hobson, an Enlishman who advises Indian producers on the marketing and utilization of mica, writes as follows in the Bulletin of Indian Industries and Labour, 1928:

> The demand frequently made by consumers for Indian mica only is often based not on any intrinsic superiority of Indian mica over that from other countries but on the more satisfactory grading and marketing of the product *** other countries are now alive to these facts, and the Indian producer must not, because of

the commanding hold India has on the market, be led to relax his efforts; instead, he should by constant attempts improve the condition in which his product is marketed so as to offset the growing competition from other countries.

Moreover, many large consumers in this country are aware of the good quality of our domestic micas.

MICA-TRADE CONDITIONS AND FUTURE OUTLOOK FOR THE DOMESTIC MICA INDUSTRY

Since 1929 there has been a heavy decrease in the consumption of all classes of mica in the United States with the exception of ground and fine byproduct mica from clay washing, the sales of which have been well maintained. This decline in consumption is illustrated graphically in figure 10[21] which shows the consumption and domestic marketed production of sheet mica larger than punch and the consumption of mica splittings in the United States from 1923 to 1933, inclusive. The primary mining of sheet mica in the United States has been drastically curtailed because of (1) decreased demand for sheet mica due to the general business depression; (2) keen competition of built-up mica, which is made almost entirely from foreign splittings; and (3) continuation of imports of foreign sheet mica which during the last 5 years have exceeded domestic production of sizes larger than punch by 4 times in both quantity and value. The heavy depreciation in the British pound and Indian rupee during the past 3 years not only cut the price at which Indian micas could be purchased in United States currency but lowered the ad valorem import duties on them correspondingly.

Table 18 shows that for the 5-year period ended December 31, 1931, only 19.4 percent by weight and 20.3 percent by value of the apparent domestic consumption of sheet mica larger than punch was supplied by domestic material. However, the actual percentage of these sizes of domestic mica in finished products was considerably less because domestic mica is not prepared as carefully as imported material with respect to the removal of imperfections and there is considerably more waste in using it. If domestic mica were trimmed to equal India grading it would lose 20 to 30 percent of its weight, and if account is taken of the fact that foreign micas are trimmed more closely it is evident that domestic consumers are actually dependent upon foreign sources for considerably more than 80 percent of sheet mica larger than punch.

It is impossible to determine the proportion of domestic consumption of punch mica supplied by domestic production, as a great deal of punch mica is sorted from imported scrap. However, the unit value of punch mica is so small that the entire sales of domestic product in 1933, amounting to 253,243 pounds, were valued at only $10,199. Punch mica is therefore of very minor importance in the industry.

With regard to mica splittings domestic consumers are almost entirely dependent on importations. Only a small quantity of splittings is produced in the United States, and a large proportion of these is amber splittings made from foreign mica. The uses for built-up mica have expanded rapidly and are encroaching each year upon those for sheet mica. Because of the adaptability of the built-up product and its cheapness as compared with sheet mica, its use will presumably continue to expand and thereby increase the dependence of domestic consumers on adequate supplies of foreign splittings. The development of new binders, such as glyptal and other synthetic resins and of inorganic binders (which are superior to shellac for making built-up mica for certain purposes) has been an important factor in extending its uses. The preponderant importance of splittings in the mica trade is illustrated by figure 10, which shows that during the last decade the quantity and value of imported splittings have always greatly exceeded those of domestic and imported sheet combined and have been 3 to 25 times those of domestic sheet.

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[21] Horton, F. W., and Stoddard, B. H., Mica: Minerals Yearbook, 1934, Bureau of Mines, p. 2.

TABLE 18.- Sources of supply of domestic consumption of sheet mica larger than punch

Imports for consumption	1929		1930		1931		1932		1933		1929 to 1933, inclusive	
	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
Manufactured mica (essentially uncut sheet)	1,283,472	$729,158	872,779	$385,250	419,906	$110,808	250,011	$66,588	616,148	$165,061	3,442,316	$1,456,865
Cut mica	118,224	201,632	72,402	100,498	16,707	19,774	23,097	16,824	39,787	25,609	270,217	364,337
Total imported sheet	1,401,696	$930,790	945,181	$485,748	436,613	$130,582	273,108	$83,412	655,935	$190,670	3,712,533	$1,821,202
Domestic production of sheet larger than punch sold or used by producers	283,084	187,332	211,703	116,077	205,306	78,513	80,485	37,906	111,297	42,980	891,875	462,808
Apparent consumption of sheet	1,684,780	$1,118,122	1,156,884	$601,825	641,919	$209,095	353,593	$121,318	767,232	$233,650	4,604,408	$2,284,010
Percent of apparent consumption supplied by domestic production	16.8	16.8	18.3	19.3	32.0	37.5	22.8	31.2	14.5	18.4	19.4	20.3

A bright spot in the outlook for domestic mica mining is that sales of fine mica by domestic producers in 1933 totaled 19,661,005 pounds and established a new high record as to quantity in spite of the business depression, a fact which apparently indicates a greater appreciation of its usefulness in the industries employing it. Sales of scrap by domestic producers in 1933 amounted to 8,751 short tons, an increase of 24.3 percent as compared with those in 1932. Much of the mica listed as scrap was fine mica derived as a byproduct of clay-washing in North Carolina, but the figures do not include a round tonnage of fine mica recovered by grinding mica schist. Imports of scrap mica in 1933 amounted to 1,619 short tons, so domestic consumption of fine mica during the year exceeded 10,000 short tons.

Another encouraging feature is the recent rise of the pound and rupee in terms of the dollar, which will in some measure tend to help the domestic mica-mining industry.

Under existing conditions, however, there can be virtually no worthwhile mining in the United States primarily for sheet mica and the small domestic production will continue to be largely a byproduct of feldspar mining or the mining of mica for scrap. The electrical industries, in which mica is an essential, and other consumers of sheet and built-up mica in the United States are almost entirely dependent upon foreign sources of supply. If deliveries from these sources were interrupted, as they were during the World War, a sheet-mica mining industry in the United States would be of paramount importance to domestic consumers, and it is hoped that conditions in the trade may so improve as to allow the survival of the domestic industry.

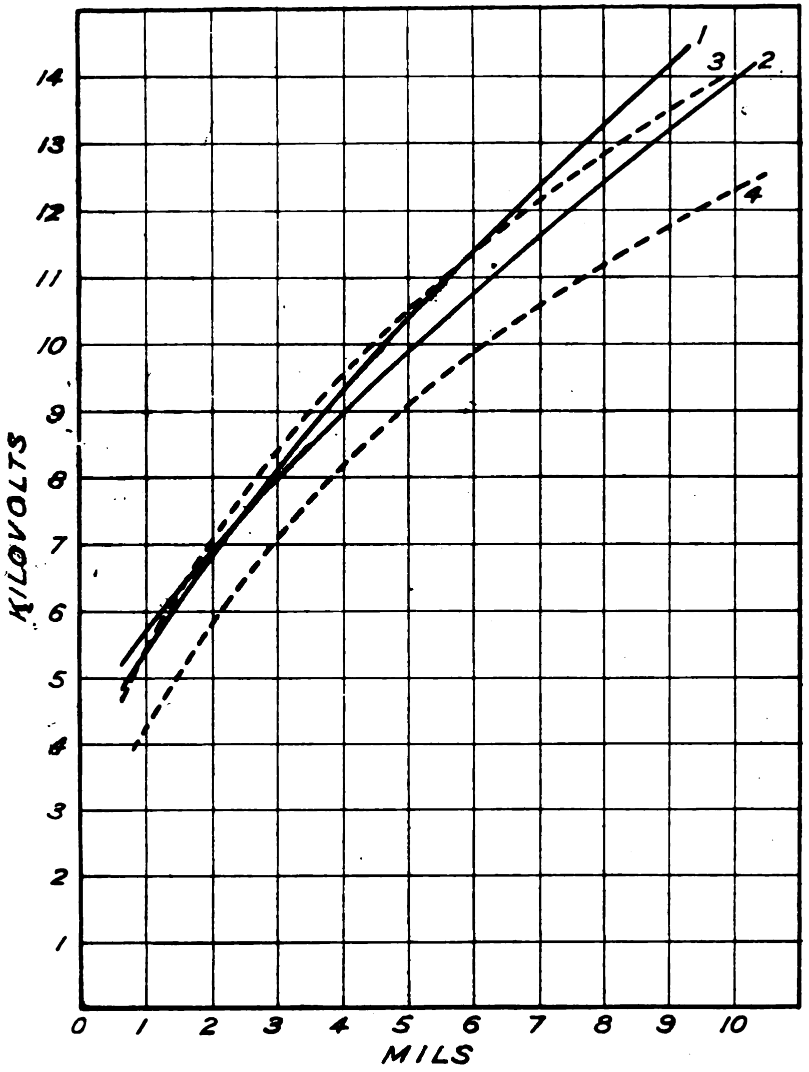

Figure 9.—Average dielectric strengths of four groups of muscovite specimens: 1, Domestic clear ruby mica; 2, domestic stained ruby mica containing air bubbles; 3, Indian clear ruby mica; 4, Indian stained ruby mica containing air bubbles.

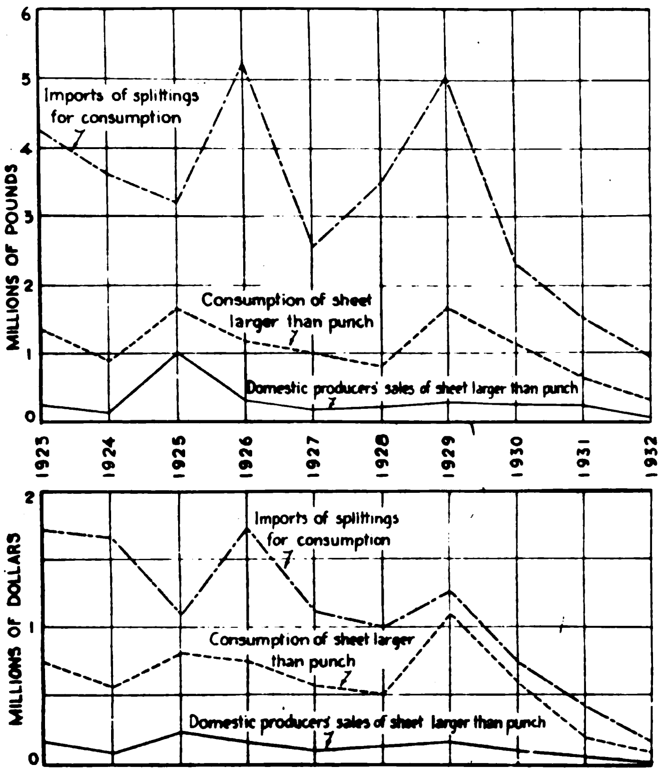

Figure 10.—Trend in consumption and value of mica.